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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

A groundwater study was carried out in the townsite of Wagin. It aimed to accelerate the implementation of effective salinity management options. The study consisted of a drilling investigation, expansion of a piezometer network, a pumping test, groundwater flow modelling and flood risk analysis.

At the sites drilled, regolith thickness ranged from 16 to 44 m. A wedge of alluvial sediments, underlain by at least 10 m of granite saprolite, was identified below valley floor sites within the townsite. The sediments were about 20 m thick below southern parts of the town and thinned towards the slopes, where the regolith consisted of weathered granite overlain by colluvium.

The watertable was shallow below large areas of the townsite. At south-eastern monitoring sites it was within 1 m of the ground surface. At most sites on mid and upper slopes, water levels in piezometers were at least 6 m deep. However, at a site located on a lineament along the northern boundary of the town (which was identified in aerial photographs), the groundwater was above ground level.

The electrical conductivity values of groundwater samples from the bore and piezometer network were between about 400 and 4,000 mS/m, and at most sites the values were greater in shallower bores.

It was deduced that a substantial proportion of the groundwater recharge that affected groundwater below the town occurred within the townsite. It was inferred from lineaments evident in aerial photographs and zones of groundwater discharge in the agricultural catchments upslope that groundwater barriers were impeding the flow of groundwater towards the town in some places. The townsite is elevated above the level of the Coblinine valley floor, and groundwater levels fall towards it. Unless groundwater mounds form during times of flood in the valley, then it is unlikely that groundwater flows towards the town from the Coblinine valley system.

The flood risk assessment for the town concluded that there may be localised flooding following rainfall events with average recurrence intervals greater than 20 years. But with larger rain events with average recurrence intervals of greater than 50 years, a considerable area of the town would be affected. The impact of such flood events on groundwater levels below the town is not known.

There are opportunities to reduce recharge, particularly within the townsite, and groundwater pumping may be worthy of further investigation. It was recommended that the current and future costs of salinity in the townsite be assessed and used to determine an appropriate level of investment in management. However, approaches to reducing recharge within the townsite should be adopted where there were additional benefits in doing so.

Contents

List of figures

List of tables

1. Introduction

The Rural Towns Program commissioned a groundwater study of the Wagin townsite. It was part of a larger investigation (called the Community Bores Project) which covered 23 towns and aimed to accelerate the implementation of effective salinity management options.

For Wagin, the groundwater study included a drilling program, a pumping test, groundwater flow modelling and a flood risk analysis. This report documents the background information for the town and its catchment (Section 2) and the hydrogeological and flood risk investigations (Sections 3 to 5). It then recommends steps for managing the salinity issues of the town effectively (Section 6).

2. Background information

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Rising watertables and salinity have been serious concerns for the Wagin community for many years. Rising damp has damaged buildings and streets, particularly on the lower slopes within and surrounding the central business area. Salinity affects an extensive area on the south-east of the town and extends up drainage lines into the townsite.

The Wagin Land Conservation District Committee had previously commissioned a consultancy to assess the rising groundwater problem in the town (Soil and Water Resources Group 1997). Following this, the Shire of Wagin commissioned a salinity management strategy (PPK Environmental and Infrastructure Pty Ltd 2000). The Shire has an on-going program to extend the mains sewerage system and improve surface water drainage within the town.

2.1 Description of the town and catchment

Wagin (117°20’E, 33°18’S) is 225 km south-south-east of Perth (Figure 2-1) and has a population of 1,400. The town is primarily a service centre with agricultural support industries for the district. It is a railway node for eastern and southern lines and the location of fertiliser and grain bulk handling facilities in the town take advantage of this. The town supports a senior high school and a district hospital. Wagin is the host for the annual Woolorama sheep and wool expo, which attracts visitors from all over the State.

Wagin lies within the Dordemunning catchment, which extends from Badgarning Rocks, 6 km west of the town, to Wagin Lake, just south of the town (Figure 2-2). The elevation at Badgarning Rocks is 388 m and at Wagin Lake is 250 m. The catchment covers about 3,000 ha, of which about 310 ha is remnant vegetation. The densely-settled part of the town covers about 300 ha, but if small-holdings and industrial land uses are included, the town area is about 995 ha.

Land use in the surrounding region is mainly annual crop production and livestock grazing. Sand and gravel extraction occurs in reserves and remnant vegetation north and north-east of the town.

2.2 Geology

The catchment is underlain by granitoid rocks. Near Wagin townsite, no faulting or mafic dykes are indicated on the 1:250,000 geology map (Chin and Brakel 1986).

The main part of Wagin is located on Quaternary colluvium and minor alluvium and the valley floor to the south-east is on a Tertiary alluvial unit (Chin and Brakel 1986). The colluvium and minor alluvium unit is associated with sandy and gravelly soils in the upper parts of the landscape and duplex soils on the middle and lower slopes. This unit overlies a Tertiary lateritic profile of variable thickness, which is made up of mottled and pallid, light to medium clays over coarser, partly-weathered granite, over 'fresh' granitic bedrock. There is an exposure of biotite granite on the railway reserve north of the intersection of Ventnor and Leonora Streets (Figures 2-3 and 2-4). Several lineaments were identified in aerial photographs (Figure 2-2) and one passes through or near to the exposure (Figure 2-3).

2.3 Climate

Summers are hot and usually dry and winters cool and usually wet. Average daily temperatures range from a minimum of 5.7°C and maximum of 15.2°C in July to a minimum of 14.4°C and maximum of 31.0°C in January (Bureau of Meteorology 2000).

Wagin is in a medium rainfall zone with a relatively low evaporation rate. The town receives an average of 439 mm of rain each year of which about 336 mm falls from May to the end of October (Bureau of Meteorology 2000). Though most rain falls during this period, substantial falls can occur over summer and autumn in some years. Rainfall for the 12 months prior to the Community Bores Project was atypical: the December and January rainfall was well above average and the autumn and winter rainfall well below average.

Average annual evaporation at Wagin is 1,650 mm (Bureau of Meteorology 2000, pers. comm.).

2.4 Drainage

The townsite straddles the lower parts of several catchments, the largest of which is the Dordemunning catchment. Surface run-off leaves the catchment via Dordemunning Creek, a 4th order stream, and flows into the saline, ephemeral Wagin Lake, 1 km south of the town (Figure 2-2). Wagin Lake discharges via two nearby lakes into the Coblinine River, the elevation of which is about 3 to 5 m lower than the lowest residential sections of the town. A smaller, unnamed drainage line (its catchment boundary is shown east of the Dordemunning boundary in Figure 2-2) that drains land lying along and to the east of the railway line has been captured in surface drains constructed by the Wagin Shire Council. The drains discharge onto salt-affected land well to the south-east of the town.

The watercourses are well-defined and well-drained on the slopes. However, the Coblinine River, which is to the south and east of the town, is a broad flat palaeodrainage system and links a series of lakes which lead into the Beaufort River downstream (Figure 2-1). Drainage within the town has been augmented by a system of concrete-lined channels linked into the creeks. At the lower end of the town, flow in the drains was restricted by accumulated silt in June 2000 and a program of desilting was underway. Due to the flatness of the land between Bullock Hills Road and the Great Southern Railway line (Figure 2-3), natural drainage is poor and the soil is waterlogged and severely salt-affected. Shallow drains installed in this area have improved drainage (Kirk, L. July 2000, pers. comm.).

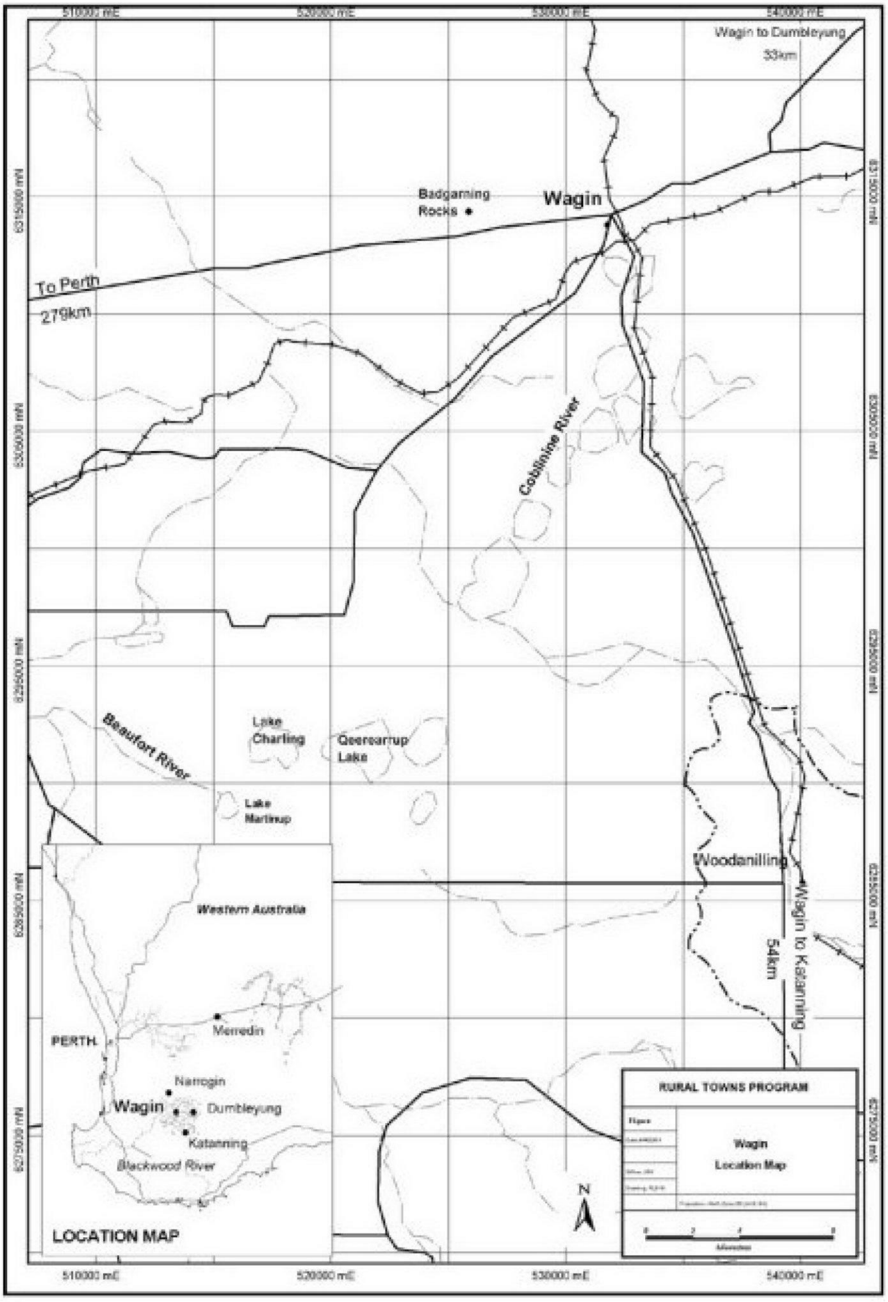

Figure 2-1. Regional location of Wagin

2.5 Hydrogeology

The 1:250,000 hydrogeology map of the region (McCombe and Ye 1999) indicates:

- minor brackish to saline supplies in local groundwater systems in weathered granitic profiles;
- minor to moderate, brackish to saline supplies in local groundwater systems in surficial aquifers associated with alluvial sediments; and
- possible moderate to major groundwater resources, brackish to hypersaline, in palaeochannel aquifers concealed by the younger overlying alluvial sediments along the Coblinine valley floor.

The Soil and Water Resource Group (1997) report suggested that recharge in deep sandy duplex soils surrounding the town to the north and in the upper catchment may be contributing to rising watertables in the town. However, aerial photographs and site inspections showed that there are groundwater discharge sites in the catchment above the townsite. This indicates that there is not hydraulic continuity between groundwater bodies in the upper parts of the catchment and below the town.

Saline discharge areas are visible along creeklines and drainage depressions passing through the town and most extensively extending away from the south-east of the town into the Coblinine system. Saline areas in creeklines often coincide with lineaments observed in aerial photographs.

2.6 Town water supply and disposal

About 300,000 kL of water is piped into the Wagin town annually by the Water Corporation to between about 750 and 800 households (Diminski, H., Water Corporation, 2000, pers. comm.). Around 90 per cent of the households are connected to the mains sewer system, so only about 10 per cent rely on septic systems. The sewerage treatment ponds are south of the townsite (Figure 2-3).

A dam to the north of the townsite (Figure 2-3) stores surface water harvested from the slopes above it and the water is used to irrigate the sports oval which is in the north-west of the townsite.

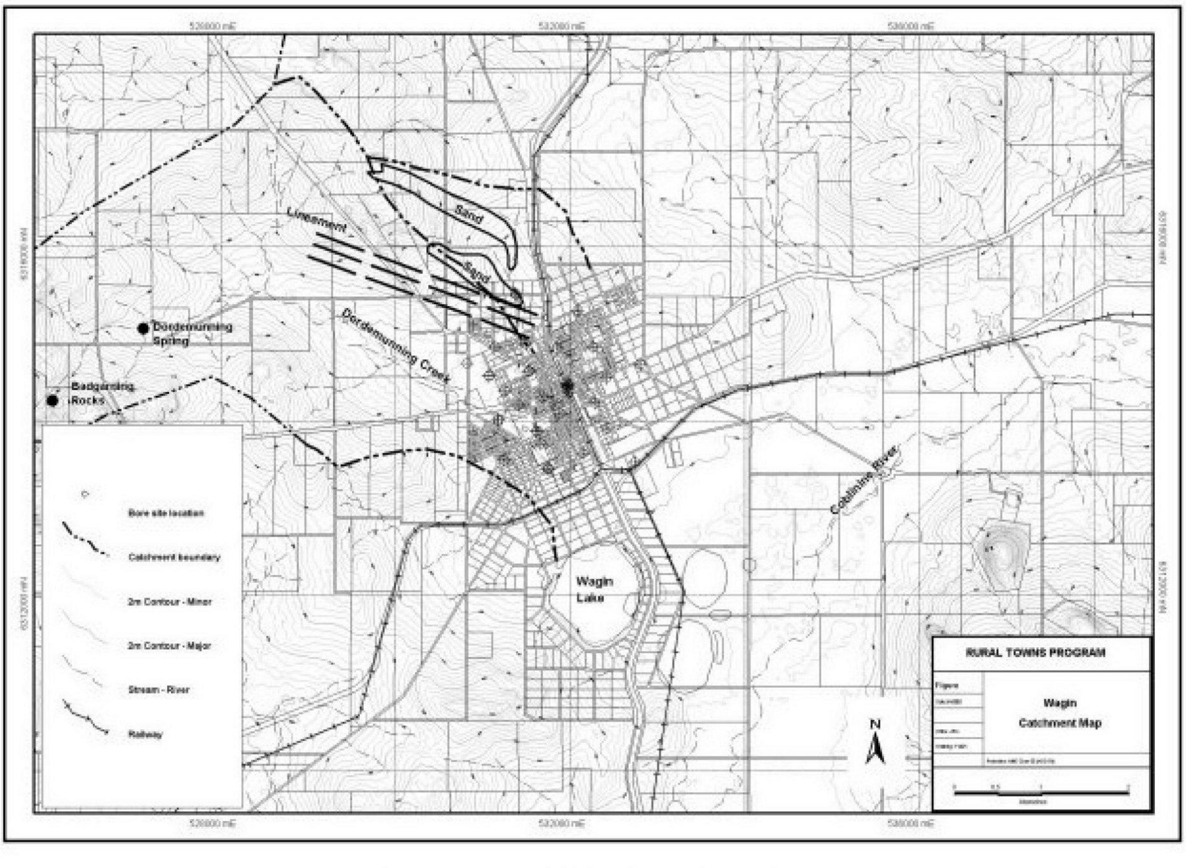

Figure 2-2. Location of the town of Wagin in its catchments

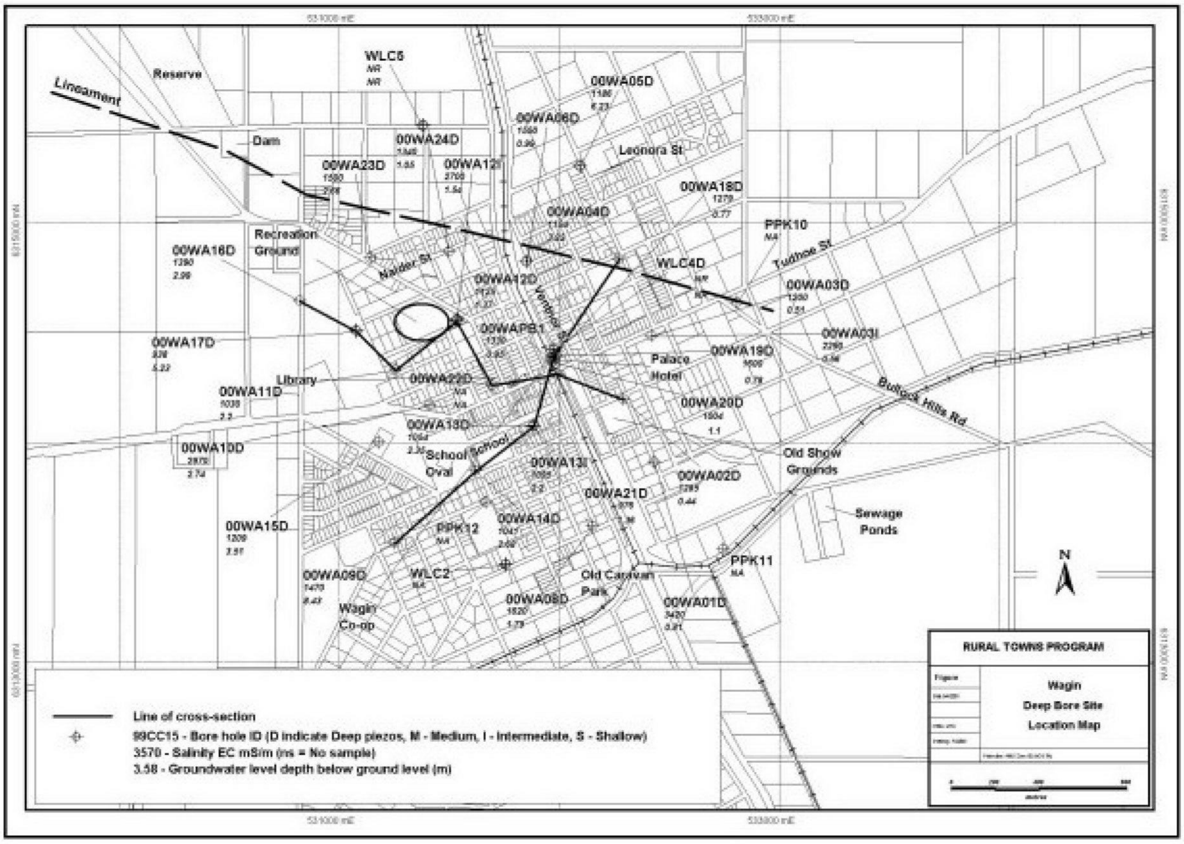

Figure 2-3. Map of deepest drilled sites within the Wagin townsite with their groundwater level depths and EC values (16 August 2000) and the locations of cross-sections (Figures 3-1 and 3-2); NR – no record

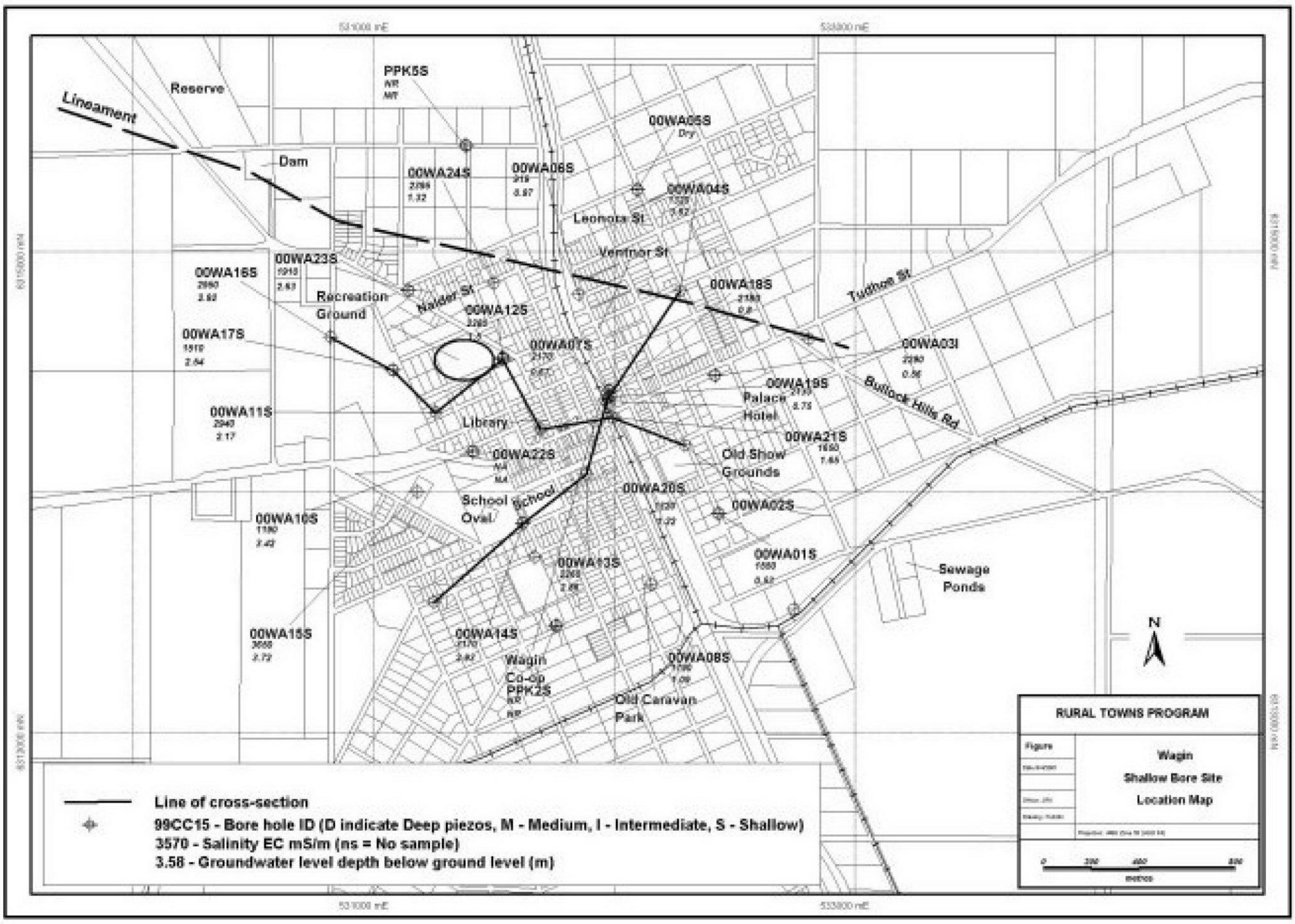

Figure 2-4. Map of shallowest drilled sites within the Wagin townsite with their groundwater level depths and EC values (16 August 2000) and the locations of cross-sections (Figures 3-1 and 3-2); NR – no record

3. Hydrogeology investigation

Authors: Edward K. Crossley, Catchment Hydrology Group, Agriculture Western Australia and Fay Lewis, Fay Lewis Consulting

The groundwater study included a drilling program coupled with the installation of a piezometer network, a pumping test and groundwater flow modelling. Most of the investigation and interpretations of the results are described in Sections 3.2 to 3.4. The information gained led to recommendations for salinity management (Section 3.4.2) and the effects of some of these were then tested using the groundwater flow model (Section 4).

3.1 Pre-existing information

Data available for preliminary desk top study and drill site selection consisted of:

- two-metre elevation contours showing natural surface water drainage (produced by the Spatial Resource Information Group, Agriculture Western Australia);
- 1:250,000 regional geology mapping (Chin and Brakel 1986);
- 1:250,000 regional hydrogeology mapping (McCombe and Ye 1999);
- Wagin Dordemunning Groundwater Study report (Soil and Water Resources Group 1997);
- Bore logs from drilling in 2000 (PPK Environmental and Infrastructure Pty Ltd 2000);
- 1:25,000-scale colour aerial photographs (Department of Land Administration in 1996).

There were a number of pre-existing observation bores and piezometers in the Dordemunning catchment. Those of relevance to the current study are WLC1, WLC2, WLC4D, WLC5, WLC8, PPK2S, PPK5S, PPK8D, PPK10, PPK11, PPK12 and 99WA01 (locations are shown in Figures 2-3 and 2-4). Unfortunately, little long-term monitoring of these has been undertaken. In some Agriculture Western Australia databases, a few of these piezometers have been renamed. Aliases are given in Table 3-1.

Table 3-1. Piezometer aliases

Original name	Other name
WLC1	00WA15D
WLC8	00WA12S
PPK8D	00WA12I
99WA01	00WA17S

The WLC bores were installed with reverse circulation air-core methods with an 89 mm-diameter bit and cased with 50 mm-diameter class 9 PVC pipe (Soil and

Water Resources Group 1997). All WLC bores have screens with 0.40 to 0.50 mm-wide machined slots.

The PPK bores were drilled in February 2000 using an auger rig (bit size unspecified) and cased with 50 mm-diameter class 9 PVC pipe with hand-slotted screens (PPK Environmental and Infrastructure Pty Ltd 2000). These bores were gravel-packed with 'blue metal' and bentonite-sealed and back-filled to the surface with drill cuttings.

Site 99WA01 was drilled by Agriculture Western Australia using an auger rig and cased with 50 mm-diameter PVC pipe with a screen of 0.2 mm-wide machine slots. The annulus was gravel-packed with '8x16' graded sand (about 1.2 to 2.4 mm diameter) and back-filled to the surface with drill cuttings. Table 3-2 contains details of all bores.

3.2 Method

A drilling program was undertaken in the townsite from 11 to 24 July 2000. A total of 45 bores were drilled at 25 sites (Figures 2-3 and 2-4). Of these, 31 were constructed as piezometers between 4.9 m and 43.0 m deep and 13 were constructed as observation bores between 3.4 and 4.5 m deep. A production bore (00WAPB1) was installed to a depth of 28 m.

3.2.1 Drill site selection

Drill sites were selected to determine depth to bedrock and regolith and aquifer characteristics of all landscape units within the Wagin townsite. Care was taken to ensure adequate bore coverage. Sites were chosen so that all neighbouring bores (existing and new) would be within 250 to 500 m of each other. Adjustments were made where necessary to avoid town infrastructure, power lines and underground phone lines, and water and sewage facilities.

At most sites, shallow and deep bores were installed to compare the hydraulic heads at different depths. At site 00WA09 only a deep bore was installed. At sites 00WA07, 00WA12, 00WA15 and 00WA17 single bores were installed to complete nests with pre-existing bores. At site 00WA13, shallow, intermediate and deep bores were installed. At site 00WA03, deep and intermediate bores were installed.

A production well (00WAPB1, see Figure 2-3) for an aquifer test was installed in a high-yielding site. The site was chosen to establish the potential for groundwater pumping within the town’s central business area and for convenient disposal of the water from the pumping test into a nearby drain. Piezometer nests were installed at four sites in two transects approximately orthogonal to 00WAPB1 to monitor the pumping test. The nests were installed 15 m and 30 m from 00WAPB1 on the east transect and 30 m and 80 m on the south transect. These spacings were deemed appropriate for the planned 72-hour aquifer test.

Site 00WA13 (Figures 2-3 and 2-4) was chosen as a site for a 'Community Awareness Bore'.

3.2.2 Drilling methods

Monitoring and production bores were drilled by contractor Austral Drilling using a reverse circulation air-core rig with a 125 mm-diameter bit. Composite samples were collected at 1-metre intervals from a cyclone attached to the rig's sample hose. Some excellent samples of partly-weathered and fresh granitic bedrock were obtained. Water was injected at a number of holes to clear blockages in the sample hose. A hammer drill was used to penetrate silcrete at 00WA03I.

The production bore was drilled using mud-rotary methods with a 220 mm-diameter drill bit.

3.2.3 Piezometer, observation bore and production bore construction

The monitoring sites were constructed with 50 mm-diameter class 12 PVC casing. All piezometers and observation bores were screened for two metres at their bases with slotted (0.5 mm-wide slots) 50 mm-diameter class 12 PVC. A gravel-pack of '8x16' graded sand (about 1.2 to 2.4 mm diameter) was placed in the annulus extending 2 m above the slotted section. Cement plugs were installed above the gravel packs to the ground surface.

Bores were constructed by inserting PVC casing in the inner tube of the drill string at the completion of each hole. The drill rods were then removed and the gravel pack and cement plug installed. In a number of cases the PVC became snarled within the inner tube. The problem was overcome by filling the casing with fresh water. The extra weight allowed the PVC to remain at the bottom of the hole while the rods were removed and the gravel pack and grouting were installed in the usual way.

All piezometers and observation bores were developed about a month after construction by air-lifting for 15 to 30 minutes with a portable air compressor, and when there was sufficient groundwater, yields were estimated. Development was deemed to be complete once reasonable clarity was achieved.

The production bore was installed with 127 mm-diameter PVC casing which was slotted (0.5 mm-wide slots) from 38 m to within 2 m of the surface. The gravel pack of '8x16' graded sand was placed 2 m below ground and a cement plug completed the top 2 m.

The production bore was developed by air-lifting with the drill rig's compressor for 15 hours. At the end of development, fine sand was still evident in the bore water, indicating that a choice of finer slots and gravel pack would have been preferable at this site.

Refer to Table 3-2 for details of all bores.

3.2.4 Drill hole logging and sampling

Approximately 500 g of drill cuttings were recovered from the cyclone at 1 m intervals and bagged for possible future analysis. Field drill logs were completed at time of drilling are available at:
<http://www.agric.wa.gov.au/environment/links/RMtechreports/>. Descriptive logs

were only produced for the deepest hole at a site. The shallower bores were assumed to have the same lithologies. The lithologies at sites 00WA20 and 00WAPB1 were assumed to be the same as at site 00WA18, which was only about 15 and 30 m away, respectively.

3.2.5 Groundwater data collection and sample analyses

Groundwater levels were measured and water samples collected monthly from all bores after allowing two weeks for the watertable to equilibrate. Pre-exisiting bores were purged with compressed air and monitored in the same way as the new bores. The electrical conductivity (EC) values of the samples were measured in the Agriculture Western Australia laboratories in Perth. Results are stored on the Agriculture Western Australia AgBores database.

3.2.6 Surveying

Sites were surveyed for position and height using a dual frequency global positioning system. The accuracy of the system was within 20 mm horizontally and 50 mm vertically.

3.2.7 Pumping test

A pumping test was carried out by Test Pumping Australia to establish aquifer parameters in the sediments. The test method is described in Appendix 1.

3.3 Results

Some of the piezometer and groundwater details are listed in Table 3-2 and the changes in groundwater level and electrical conductivity across the townsite are shown in Figure 2-3 and Figure 2-4.

3.3.1 Profile descriptions

Detailed drill logs are available at <http://www.agric.wa.gov.au/environment/links/RMtechreports/>.

At valley floor sites, drilling revealed sediments up to 20 m thick overlying at least 10 m of granite saprolite. However, in contrast to the suggestion of Soil and Water Resources Group (1997) that these may be colluvial in origin, their appearance suggested that they are more likely to be alluvial sediments. Therefore, they were assumed to belong to the Tertiary sediments mapped by Chin and Brakel (1986). A common feature of holes drilled in the business district of the town along the margin of the valley unit was a thick layer of silcrete within these sediments, often extending into the top of the saprolite. The alluvial sediments thinned towards the slopes, where the regolith consisted of weathered granite with more recent (probably Quaternary) colluvium.

Regolith thickness at the drill sites varied from 16 to 44 m, indicating relatively undulating bedrock topography. The deepest basement was below an upper slope to the south-west of the town at site 00WA09 (Figure 2-3) and the drilled depth on the valley flats varied between 28 and 40 m. On the lower and mid-slopes, basement was shallower (e.g. only 16 m deep at site 00WA06 at the end of Leonora Street in the railway reserve, 50 m from the exposed granite; 22 m deep at 00WA17 near the recreation grounds; 22 m deep at 00WA22 behind the library; and 25 m deep at 00WA21 south of the Tudhoe Street railway crossing (Figure 2-3).

Figures 3-1 and 3-2 show sections parallel and orthogonal to the presumed direction of groundwater flow.

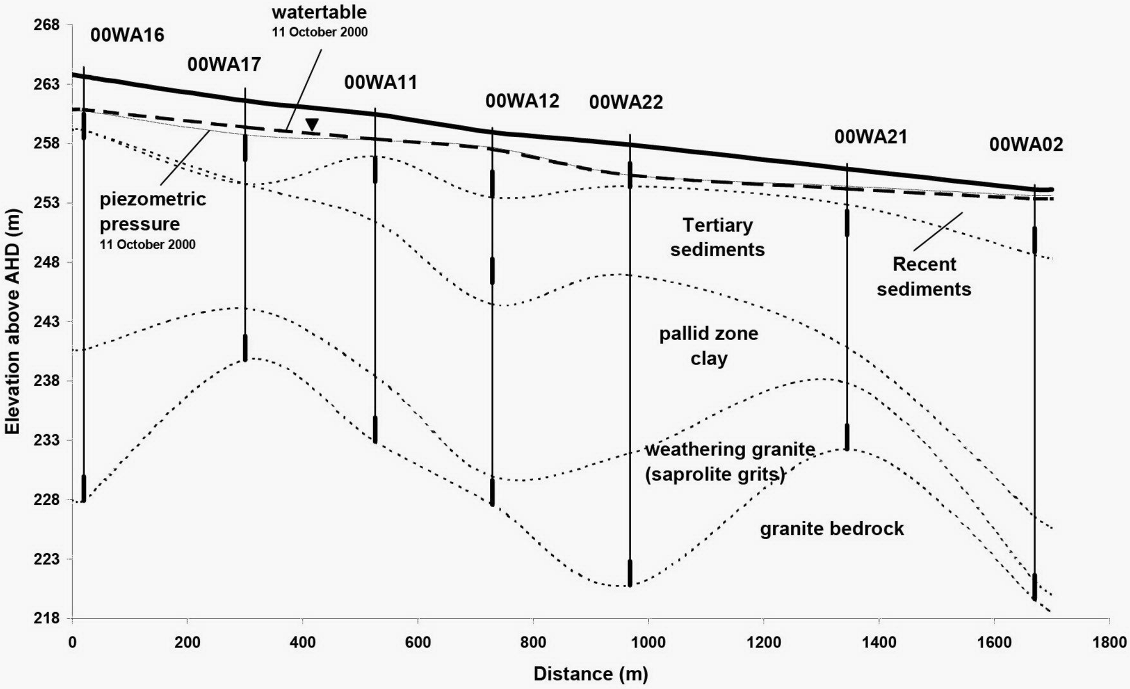

Figure 3-1. North-west to south-east cross-section (location shown in Figure 2-3)

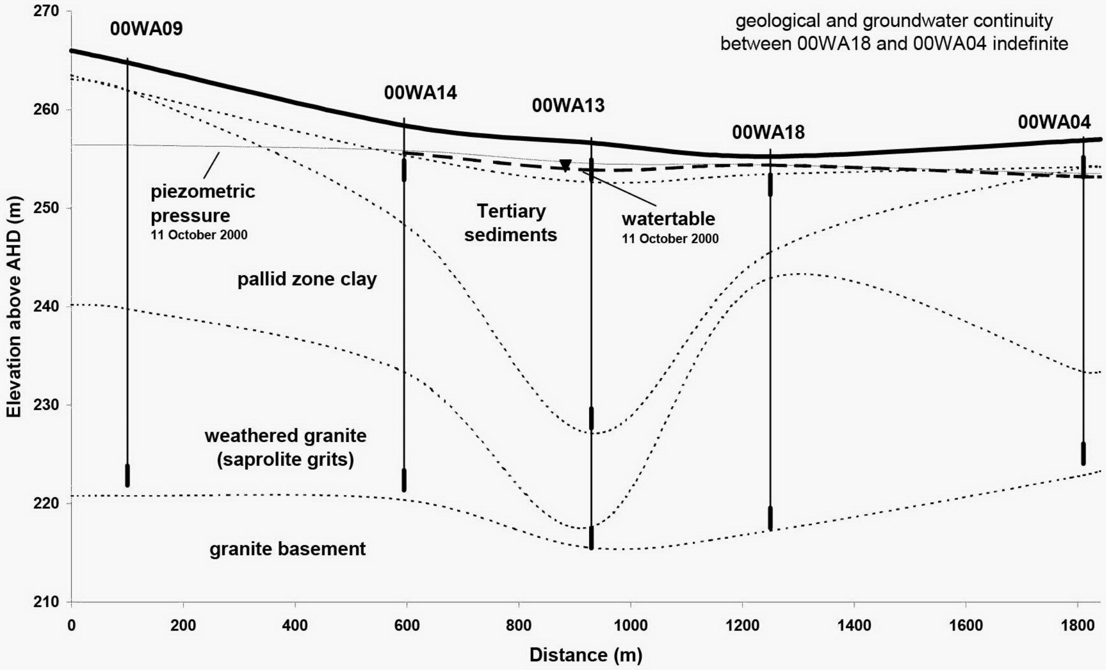

Figure 3-2. South-west to north-east cross-section (location shown in Figure 2-3)

Table 3-2. Some construction and groundwater details (monitored on 11 October 2000) for new piezometers (names begin with '00') and for pre-existing piezometers (names begin with other than '00')

Bore name	Ground level elevation above AHD# (m)	Intake interval depth bgl## (m)	Groundwater level depth bgl## (m)	Groundwater level elevation above AHD# (m)	Groundwater EC (mS/m)	Estimated yield (L/s)
00WA01D	253.2	38.86—40.86	0.82	252.4	3,210	NE*
00WA01S	253.3	1.56—3.56	0.67	252.6	2,090	~1
00WA02D	254.1	32.47—34.47	0.53	253.6	1,296	NE*
00WA02S	254.1	3.24—5.24	0.75	253.4	349	NE*
00WA03D	253.9	30.35—32.35	0.78	253.1	1,192	>1
00WA03I	253.8	6.02—8.02	0.78	253.1	2,330	NE*
00WA04D	256.9	30.79—32.79	3.34	253.5	1,139	negligible
00WA04S	256.9	1.69—3.69	DRY	<253.2		NE*
00WA05D	263.8	37.09—39.09	6.20	257.6	1,170	1.75
00WA05S	263.8	1.51—3.51	DRY	<260.3		NE*
00WA06D	257.1	14.89—16.89	0.90	256.2	922	negligible
00WA06S	257.1	1.89—3.89	0.89	256.2	1,500	NE*
WLC4D	255.1	20.46—22.46	0.74	254.4	1,007	NE*
00WA07S	255.1	1.46—3.46	0.86	254.3	2,440	NE*
00WA08D	254.7	37.98—39.98	1.47	253.2	1,600	<1
00WA08S	254.7	1.72—3.72	1.79	252.9	1,970	NE*
00WA09D	264.8	40.93—42.93	8.39	256.4	1,470	2
00WA10D	259.5	30.49—32.49	3.29	256.3	1,044	1

Table 3-2 (continued)………

00WA10S	259.5	2.52—4.52	2.62	256.9	2,940	NE*
00WA11D	260.4	25.51—27.51	2.14	258.3	1,039	<1
00WA11S	260.4	3.60—5.60	2.02	258.4	3,050	NE*
00WA12D	259.0	29.35—31.35	1.30	257.7	1,128	~1
PPK8D	259.0	10.70—12.70	1.24	257.7	2,650	NE*
WLC8	258.8	3.13—5.13	1.27	257.5	2,270	NE*
00WA13D	256.6	39.12—41.12	2.09	254.5	1,049	~2
00WA13I	256.7	26.98—28.98	2.27	254.4	1,092	NE*
00WA13S	256.7	1.75—3.75	2.78	253.9	2,380	NE*
00WA14D	258.4	35.02—37.02	2.52	255.9	1,048	NE*
00WA14S	258.3	3.47—5.47	2.69	255.6	1,313	NE*
WLC1	260.3	12.00—14.00	3.33	257.0	1,310	NE*
00WA15S	260.3	2.92—4.92	3.34	257.0	3,630	NE*
00WA16D	263.6	30.81—32.81	2.91	260.7	1,370	NE*
00WA16S	263.6	3.18—5.18	2.77	260.9	3,230	NE*
00WA17D	261.6	19.82—21.82	2.86	258.7	933	NE*
99WA01S	261.7	3.02—5.02	2.30	259.4	1,480	NE*
00WA18D	255.3	35.70—37.70	0.86	254.4	1,244	>2
00WA18S	255.3	1.86—3.86	0.88	254.4	1,770	NE*
00WA19D	255.2	32.43—34.43	0.86	254.3	1,563	NE*
00WA19S	255.2	1.67—3.67	0.83	254.4	1,320	NE*

Table 3-2 (continued).........

00WA20D	255.6	31.51—33.51	1.19	254.4	999	NE*
00WA20S	255.6	2.93—4.93	1.29	254.3	1,640	NE*
00WA21D	255.9	21.59—23.59	1.45	254.4	982	NE*
00WA21S	255.9	3.57—5.57	1.70	254.2	1,650	NE*
00WA22D	257.9	35.11—37.11	2.57	255.3	811	>1
00WA22S	257.9	1.55—3.55	2.54	255.4	3,460	NE*
00WA23D	262.5	34.04—36.04	2.60	259.9	1,500	~2
00WA23S	262.5	1.75—3.75	2.57	259.9	2,300	NE*
00WA24D	258.8	35.45—37.45	1.00	257.8	1,340	~2
00WA24S	258.8	1.78—3.78	1.20	257.6	1,760	NE*
00WAPB1	255.5	2.08—38.08	1.04	254.4	1,330	~4
PPK2S	255.8	5.53—7.53	1.80	254.0	1,980	NE*
WLC2[###]		22.6—28.6				NE*
WLC5	261.2	14.35—16.35	-1.70	262.9	765	NE*
PPK5S	261.1	5.11—7.11	-0.05	261.2	1,094	NE*
PPK10	252.4	7.01—9.01	0.35	252.1	3,190	NE*
PPK11	251.6	2.88—4.88	0.69	251.0	2,920	NE*
PPK12	257.3	4.08—6.08	2.16	255.1	916	NE*

#: AHD - Australian Height Datum; ##: bgl - below ground level; ###: this bore has been filled with stones; *: NE – not estimated

Wagin overlies two distinct types of regolith. In the lower areas of the town, on the valley flats, the regolith comprises colluvium and alluvium that overlie granite saprolite weathered *in situ* (i.e. residual). The sediments become thinner with distance upslope from the valley floor and in the higher parts of the town, the regolith comprises only colluvium overlying granite saprolite. The granite saprolite becomes thicker with distance away from the valley unit.

The alluvium consists of up to 25 m of sandy clays to clays, inter-layered with fine- to coarse-grained sands, up to 6 m thick. The layers could not be traced between drilled sites and were assumed to be lenses. Colours included red, yellow and pallid grey. Silcrete and ferricrete hardpans (up to 2 m thick in places) interspersed through the sediments were not continuous and contained small, iron-stained pores.

Away from the low-lying valley sites, 1 to 2 m of colluvium overlie up to 20 m of saprolite clay which in turn lay over up to 15 m of saprolite grit and granite saprock. The saprolite clay zone typically comprised up to 20 m of pale grey to yellow sandy clay, often highly micaceous and occasionally indurated in thin bands. On the upper slopes, gravel or yellow sandy colluvium overlay the saprolite. At these sites the clays were often goethite- or haematite-altered.

The saprolite grit/saprock layer consisted of up to 15 m of mostly yellow to grey gravelly sandy clay and gravelly clayey sand with quartz and felspar crystals up to 10 mm-diameter and occasionally partly indurated. Biotite crystals were also abundant in most holes. An exception was a quartz-rich regolith that was encountered at 00WA17, where samples contained large quartz fragments, increasing in proportion through the saprock to the basement.

In most holes, the saprock returned in the sample was in laminar chips with some iron staining on the horizontal faces. This indicated extensive fracturing in the upper zone of the bedrock.

3.3.2 Groundwater levels

In Wagin, depth to watertable was largely a function of landscape position (see Figures 3-1 and 3-2):

- East of the railway line, in the lower areas, watertables were within 1 m of the surface on each monitoring date, including December 2000. Total head gradients were slightly upward at the old show grounds and near the Palace Hotel.
- In the lower parts of the town west of the railway, watertables monitored in October 2000 ranged from 1.2 m below surface at Nalder Street (site 00WA24) to 3.3 m below surface; most were around 2.5 m deep. Heads were upward at the school (site 00WA14), the old caravan park (site 00WA08), the Wagin Co-op (site 00WA13) and Nalder Street.
- In higher parts of the town, watertables monitored in October 2000 were deeper than 3.3 m. Shallow bores were dry in October and piezometric heads were at least 6 m below ground level under the mid-slopes and greater than 8.4 m deep under upper slopes.

Piezometers WLC5 and PPK5S are sited on one of the lineaments identified in aerial photographs (Figure 2-2). In September 2000, the water level in WLC5 was 0.4 m *above* ground level, and that in the shallower piezometer was at ground level. The levels in both piezometers rose from September to December, the former by about 1.4 m, the latter by about only 0.1 m. No other piezometers in the network had water levels above ground, and none of them was located directly on any of the identified lineaments.

Groundwater levels in bores established by Soil and Water Resources Group in 1997 were around 30 cm lower in May 2000 than when previously measured in May 1997.

3.3.3 Groundwater electrical conductivity

There was a substantial difference in EC values for shallow and deep aquifers. August 2000 measurements of groundwater in shallow bores returned EC values of between 450 and 3,650 mS/m, with a mean value of 2,110 mS/m. All but three shallow bores had higher values than the adjacent deep bores. The piezometer field EC values were between 920 and 3,420 mS/m but averaged only 1,400 mS/m. The highest values were from the deep aquifer at site 00WA01D (near the grain depot) and from shallow watertables measured in bores opposite the shire offices (00WA10S), behind the tennis courts (00WA11S), south of the caravan park (00WA15S) and north-east of the Woolorama grounds on Rifle Road (00WA16S). EC values from August 2000 are shown in Figures 2-3 and 2-4 and values from October 2000 are listed in Table 3-2.

3.3.4 Groundwater yields and pumping test drawdowns

A number of piezometers with screens in saprolite grit achieved air-lifted flows estimated at up to 2 L/s (170 m^3/day) during development (Table 3-2) indicating transmissive aquifers in the saprolite grits.

The air-lifted estimated flow rate at the production bore was about 4 L/s (350 m^3/day). This was similar to the rate of 3.5 L/s (300 m^3/day) chosen for the three-day pumping test, but the groundwater levels were still falling at the end of the test (Figure 3-3), so it is not clear whether this rate could be sustained for long periods.

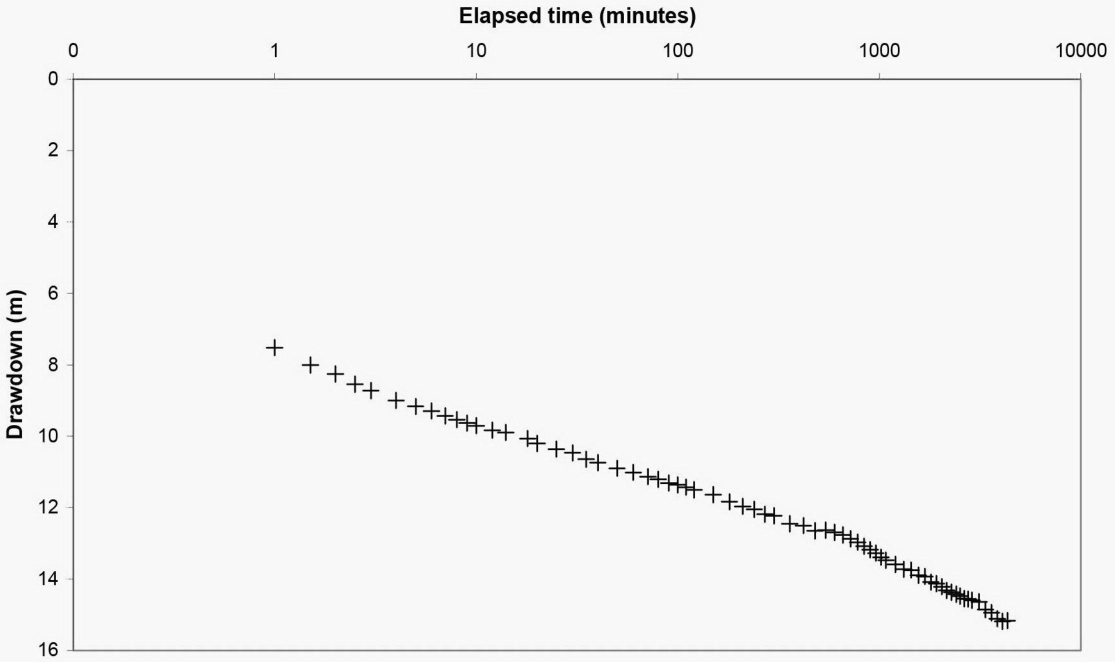

Figure 3-3. Production bore drawdown versus time for the constant rate test (pump rate was 3.5 L/s)

The drawdown curve in the production bore steepened after about 600 minutes, and this steepening was repeated in the deep piezometers drawdown curves (Figures 3-4 and 3-5). The records supplied by Test Pumping Australia did not show any change in pumping rate, but the drawdown curves of several of the shallower monitoring sites flattened sharply at different times, both before and after the change in the production bore drawdown curve. This indicates that water was withdrawn from shallow depths initially, but not later, and that more water was then withdrawn from the deeper locations to compensate. None of the shallow monitoring piezometers or observation bores dried out during the test.

Sites 00WA20 and 00WA21 are south of the production bore. Site 00WA07 is to the north-north-east and sites 00WA18 and 00WA19 are to the east. At the end of the constant rate test, the watertable drawdown at site 00WA20 (about 30 m from the production bore) was nearly 2.3 m and that at site 00WA21 (about 80 m from the pumped bore) was about 1.4 m (Figures 3-4 and 3-5). However, watertable drawdowns at the three eastern and northern monitoring sites were less, even at those sites nearer to the pumped bore. Similarly, the drawdowns in the deeper piezometers to the south were large compared to those to the east and north when distance from the pumped bore was taken into account. This indicates that the 'cone of depression' around the pumped bore was anisotropic. Drawdown increased with depth of intake interval at a site.

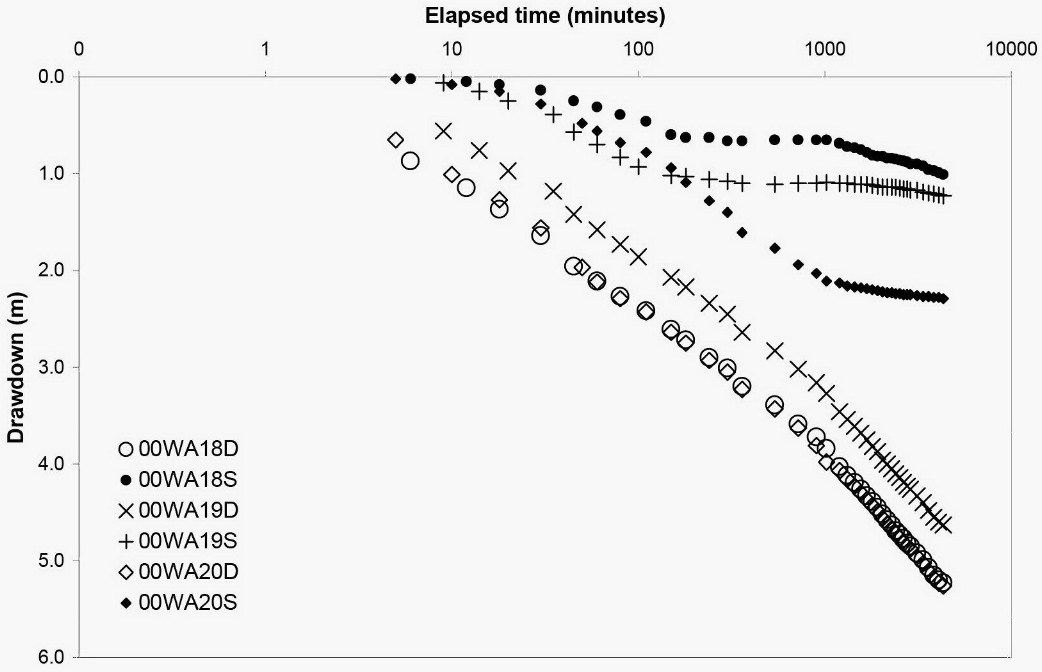

Figure 3-4. Drawdowns in monitoring piezometers at about 15 m (site 00WA18) and about 30 m (sites 00WA19 and 00WA20) lateral distance from the production bore versus time for the constant rate test

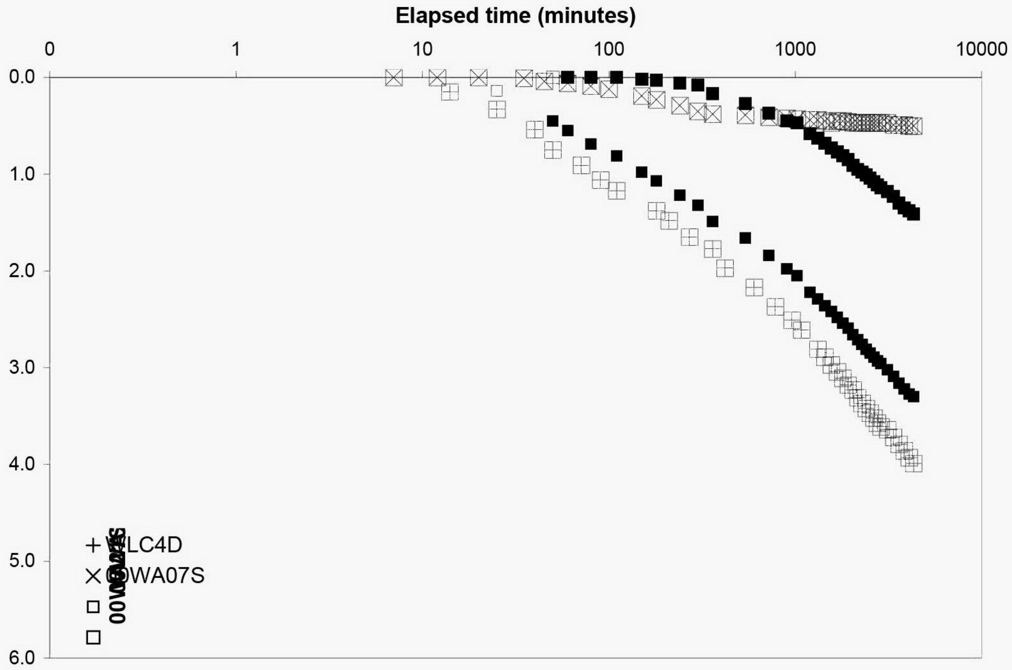

Figure 3-5. Drawdowns in monitoring piezometers at about 43 m (WLC4D and 00WA07S) and about 78 m (site 00WA21) lateral distance from the production bore versus time for the constant rate test

The transmissivities calculated by Test Pumping Australia for the pumped bore and deeper piezometers were around 30 m^2/day (Appendix 1). It is not known which parts of the drawdown curves were used to calculate these values. It is likely that different results would be produced from the early (before about 600 minutes) and later drawdown measurements. In addition, the analyses they used assumed that the pumped aquifer was homogeneous, isotropic and of infinite extent. Therefore, the calculated values for transmissivity should only be used with caution.

3.4 Interpretation and discussion

This section presents an interpretation of the recharge, groundwater flow and discharge processes affecting Wagin, based on the available information. It then discusses the risk of further salinity and the options for managing the problem.

3.4.1 Recharge

A simple zoning system for considering the sources of groundwater recharge affecting a townsite was applied to the towns in the Community Bores Project. It is described and then applied to Wagin.

3.4.1.1 The three recharge zones

The following comments assume that the recharge that causes groundwater to rise below townsites can occur in three 'zones':

1. the townsite itself;
2. the slopes directly above the townsite; and
3. the valley floor downslope of the townsite.

Within the ***townsite zone***, the contribution of water can come from:

- direct recharge from rain infiltrating into the ground where it falls;
- recharge from imported water supplies (e.g. leakages from pipes and storage facilities, overwatering, septic systems);
- indirect recharge below ponding areas which collect surface run-off generated on the slopes above the town and on the hard surfaces within the town; and
- indirect recharge below flowing surface water (seasonal creek flows, overland flow and unusual floods).

Recharge occurring on ***slopes above a townsite*** can affect groundwater levels below the town if the groundwater systems below the zones are connected. In most cases, the source of the recharge will be rain falling on the slopes and may be direct or indirect.

The groundwater system below a ***valley floor downslope of a townsite*** can affect the groundwater levels below the townsite in two ways. Rising valley groundwater levels may:

- cause the valley floor system to 'encroach' under the town; and
- inhibit the outflow of groundwater from below the town.

Again, the degree of connection between the groundwater bodies below the two zones will influence the magnitude of the effect of the downslope zone on the townsite groundwater levels. Groundwater levels in the downslope zone may be influenced by rain falling on the zone, surface water flowing into the zone from the town and the slopes above the town, and surface water and groundwater flowing in from other areas.

The relative importance of these three zones differs from town to town but cannot be quantified with only the available data. Also, the importance of the different recharge processes will vary from year to year and from season to season. However, one generalisation can be made. If a townsite (or part of a townsite) clearly has negligible groundwater input from either slopes above or a valley floor below, but still has problems caused by high groundwater levels, then it can be concluded that the water causing the problems is recharged solely within the townsite (or that part of the townsite). This is the case in several of the towns in the Community Bores Project. A further implication that can then be drawn is that townsite recharge is also likely to be an important cause of groundwater rises in other towns, even if groundwater systems from slopes above and valley floors below also make contributions.

3.4.1.2 Wagin recharge zones

In Wagin, it seems particularly reasonable to infer that the recharge within the ***townsite zone*** is important because the watertable is shallow below much of the town, so a relatively high proportion of infiltrating water can become recharge before plants have the opportunity to use it or evaporation of soil water occurs.

Of the ***slopes above the town,*** most land to the west is cleared farmland with the exception of the reserve immediately north-west of the town (Figure 2-3). Consequently, recharge within the catchment is likely to be substantial. Aerial photographs clearly show south-westerly trending linear zones of sandy and gravelly soils just north of the town (Figure 2-2). The photographs also plainly show that groundwater discharges from the sandy zones where they are crossed by a drainage line, north of the town. A number of narrower lineaments, subparallel to the Dordemunning Creek and passing through the northern parts of the townsite, are also evident in aerial photographs (Figure 2-2). Although the lineaments could represent geological features which channel groundwater flow to the groundwater systems below the townsite, it seems that they are acting as groundwater barriers and prevent inflow to aquifers below the town. This is because groundwater discharges into the Dordemunning Creek and into the un-named drainage line in the catchment to the east at sites where the lineaments cross them. Other discharge sites can be identified in the Dordemunning catchment, west of the town. The implication is that at least some of the groundwater from the slopes above the town discharges before reaching it.

Groundwater appears to have nearly filled the regolith below the ***valley floor downstream of the townsite*** since groundwater levels bores and piezometers are within 1 m of the ground surface. It is assumed that these high groundwater levels impede outflow from the groundwater systems below the town. When flooding occurs in the Coblinine valley, it is possible that a groundwater mound is created below it and that water from this dissipates into the systems below the town. There is currently no data to support this.

Long-term, frequent and regular monitoring of groundwater levels in different parts of the town and catchments can show where the important recharge areas are and when they are active. This will help to establish whether the rain is a more important factor than imported water supplies, and whether groundwater recharged above or below the town has substantial effects on groundwater levels below the town. Therefore, the network is a valuable asset.

3.4.2 Groundwater systems description

The inferred groundwater gradient in the Dordemunning catchment is from north-west to south-east. The cross-section in Figure 3-1 suggests that there is a watertable gradient towards 00WA04 from 00WA18. However, the two bores may be in unconnected aquifers as 00WA04 is north of a lineament associated with shallow bedrock near site 00WA06 (Figure 2-3).

In the weathered granite regolith under Wagin, most groundwater flow is considered to be within the saprolite grits. These are between 3 and 15 m thick, and if they are similar to those assessed by George (1992), they are likely to have saturated hydraulic conductivities in the range of 0.01 to 1.10 m/day.

The south-east section of Wagin overlies the margin of the Coblinine River palaeovalley and there are alluvial sediments (presumed to be of Tertiary age) under the lower parts of the town, thickening to the south-east. Drilling in the areas of thickest alluvium revealed numerous, permeable water-bearing layers up to 6 m thick. These layers could not be traced between the drilled sites. The piezometric heads at most sites drilled into the palaeovalley system were within 1.5 m of the ground surface and, in conjunction with a number of clay and silcrete layers in the sediments, were assumed to prevent downward groundwater flow. The shallow groundwater within the sediments has elevated salinities, considered to result from concentration by evaporation.

There was an anisotropic response to the pumping test in 00WAPB1, implying that aquifer characteristics changed substantially over small lateral distances.

In the south-east of the town, discharge is occurring from shallow watertables by evaporation. This area has been subject to prolonged concentration of salts so that only halophytic plants exist there. Salinity is also evident in the drainage lines that flow through the town, as they present a discharge path for the shallow watertable.

3.4.3 Assessment of salinity risk

There are no long-term records from which to extrapolate, but it is likely that all the low-lying parts of Wagin are at risk from groundwater discharge. This is expected to spread outward and upslope from drainage lines.

When watertable levels approach the ground surface, waterlogging is likely to worsen. Capillary rise may create 'rising damp' in buildings.

3.4.4 Management options

There are two main approaches to dealing with high groundwater levels and discharge: treat the cause by reducing groundwater recharge; treat the problem by abstracting groundwater.

By analogy with other towns, it is assumed that water management within Wagin's townsite zone is important. Monitoring where and when groundwater levels rise and fall will provide information on whether recharge only follows rainfall or occurs during dry periods too (in which case, imported water supplies will be implicated). However, it would be wise to take measures to reduce townsite recharge now and then use information gained from groundwater level records in the future to refine the recharge reduction measures.

Some **recharge reduction** measures for townsites may have other benefits, such as reduced water supply costs and dependence, less waste of good quality rain water, and less infrastructure damage from floods and surface run-on. Some measures to consider are:

- continue the replacement of septic systems with a sewer system;
- prevent surface water from ponding in areas where it may become recharge (see Section 5);
- monitor the amount of water required by gardens, parks and sports grounds and eliminate overwatering;
- check for and mend leaks in water pipes, drains, culverts, dams and pools;
- revegetate bare ground and replace grass and weeds with perennial local plants in as many locations as possible;
- encourage residents to replace some of their imported water supplies with water harvested from their own hard surfaces (roofs, drives).

The Water Corporation has an interest in reducing wastage of the water it supplies, and could be approached for assistance with some steps.

Groundwater level monitoring should be carried out monthly and records should be analysed by a hydrogeologist at least once a year. Monitoring should continue after any recharge reduction measures are taken so that the impacts can be assessed.

There is also the opportunity to reduce recharge on the agricultural land to the north-west and west of the townsite by using surface water control structures to eliminate waterlogging (which should have the added benefit of increasing production) and by increasing the area planted to perennials.

Groundwater abstraction by pumping from bores may be an effective option in some towns. However, groundwater drainage is unlikely to be effective as it only lowers groundwater levels along narrow zones either side of the drain.

The three-day groundwater pumping test in Wagin showed that the watertable was lowered more than 2 m at a monitoring site 30 m to the south, and more than 1 m at a monitoring site 78 m to the south. However, effects were less to the north-east and east (only about 1 m at a site 15 m from the pumped bore; 0.5 m at a site 43 m away). By the end of the test, the watertable was only lowering very slowly, although the water levels in deeper piezometers were draining more rapidly. It is possible that long-term pumping would be effective in lowering groundwater levels below the town, but since groundwater abstraction is expensive, may cause settlement damage to town buildings and infrastructure, and the pumped water has to be carefully used or evaporated to avoid causing groundwater problems elsewhere, the option needs careful and thorough investigation before being implemented.

A groundwater model was constructed (Section 4) to assess the impacts that a range of management options might have on groundwater levels.

4. Groundwater flow modelling

Authors: Cahit Yesertener and Shawan Dogramaci, Water and Rivers Commission

Section 3 discussed a combination of management approaches which could be effective in Wagin. This section describes a computer groundwater model which was constructed to assess the impacts of a selection of possible strategies.

Firstly, a suitable conceptual model was constructed based on the results of the drilling investigation (Section 3) and topographic and climatic data. This conceptualisation was adapted to the three-dimensional groundwater flow simulation program Visual MODFLOW 2.8 (Waterloo Hydrogeologic 1999) and the modelled head was calibrated against observed groundwater levels. The model was then used to simulate the effects of three different strategies: 'do nothing differently' to determine the impacts of inaction, groundwater abstraction by pumping and groundwater drainage.

Sections 4.1 and 4.2 describe the construction of the conceptual and computer models and the calibration of the computer model. The strategy simulations and their results are presented in Section 4.3. Please note the warnings in Section 4.5 when considering the results.

4.1 Model construction and conceptualisation

Conceptually, the groundwater model consisted of four layers: the unconfined colluvium, the leaky or semi-confined alluvial sediments, the pallid zone, and the leaky or confined saprolite of the weathered granite as defined by the hydrogeological investigation (Section 3). Inflow and lateral flow boundaries of the model domain are illustrated in Figure 4-1. The model domain covered an area of 3 km from east to west and 4 km from north to south. This area incorporated the majority of the bores in the townsite. Each cell in the domain was 20 m by 20 m, resulting in 150 columns and 200 rows, a total of 30,000 cells. The top of the unconfined/semi-unconfined layer was taken as the land surface, which was extracted from 2 m-contour digital elevation models for the catchment (map sheet 2331-2 NW, produced by Spatial Resources Information Group, Agriculture Western Australia).

This information, together with thicknesses of the four layers taken from bore logs, was interpolated using kriging and then assigned to each model node. The inflow boundaries in the north-western part of the townsite were simulated as constant head boundaries, while the outflow boundary to the south-east was simulated through a general head boundary. Catchment boundaries in the north-east and north-west corners of the modelled domain were taken as no-flow boundaries.

4.2 Steady-state model calibration

The steady-state model was calibrated against water level measurements made on 11 October 2000 and calibration was accepted with a correlation coefficient of 0.98. The standard error of estimate was 0.07 m (Figure 4-2) and the greatest discrepancy was -1.58 m in 00WA09D. The initial hydraulic conductivities for all four layers were estimated using the soil and lithological descriptions from the drilling program and the results of the pumping test (Sections 3 and Appendix 1). Based on the lithological descriptions, the hydraulic conductivities of the four modelled layers varied from the tops of the hills down-gradient towards the main drainage line (Figure 4-3).

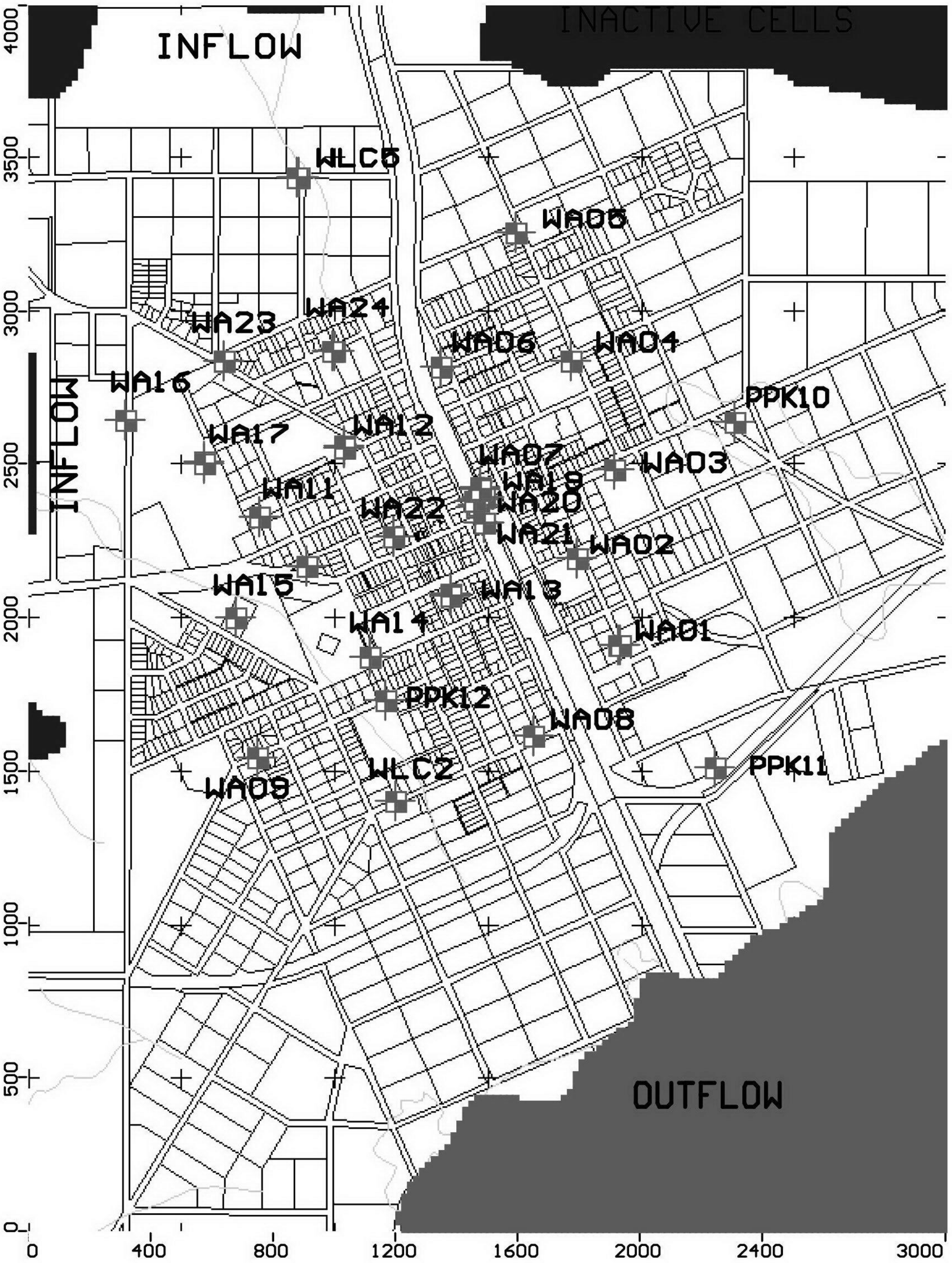

Figure 4-1. The boundary conditions (scales along axes in metres, top of map is north)

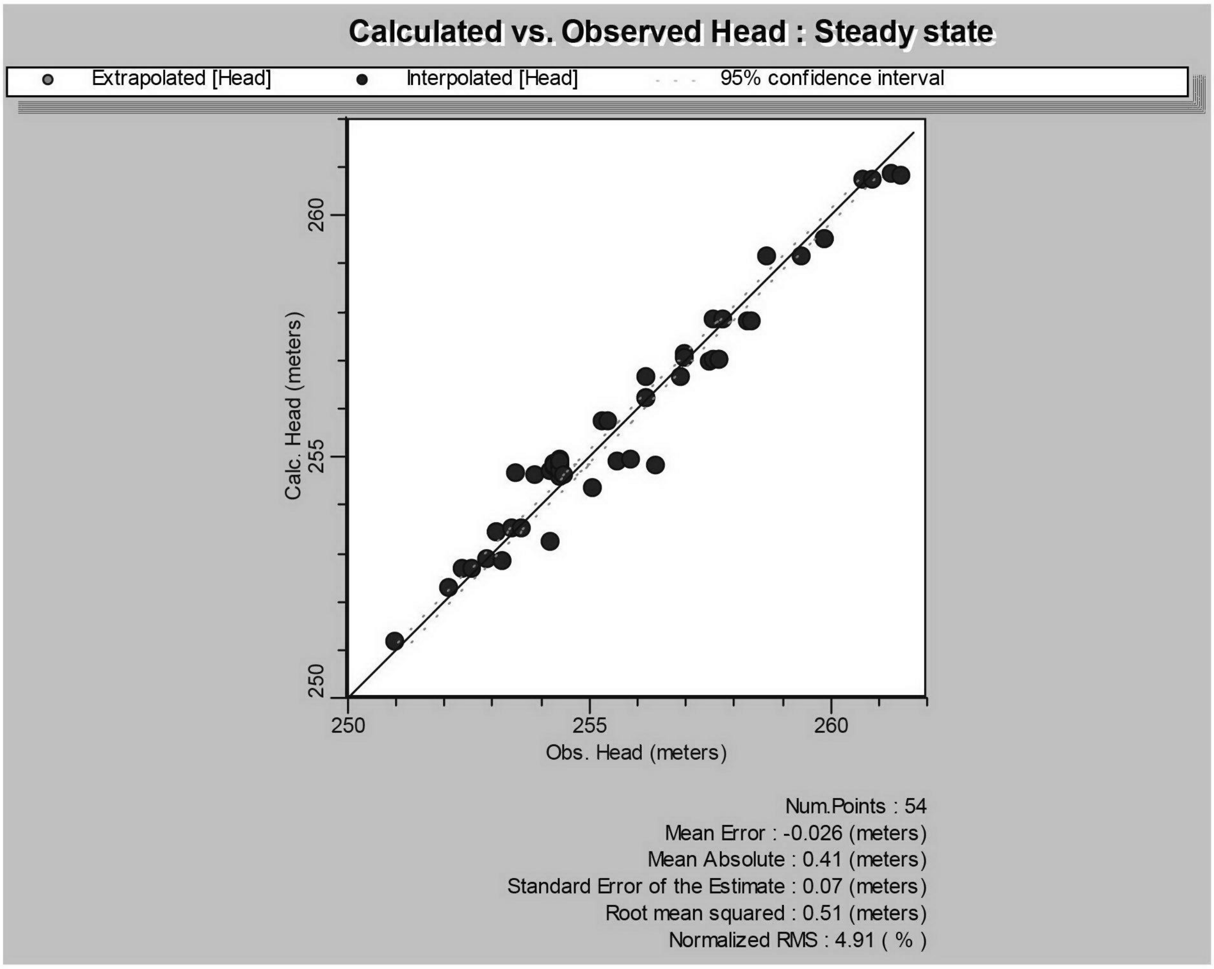

Figure 4-2. Model calibration and statistical parameters – calculated heads versus observed heads

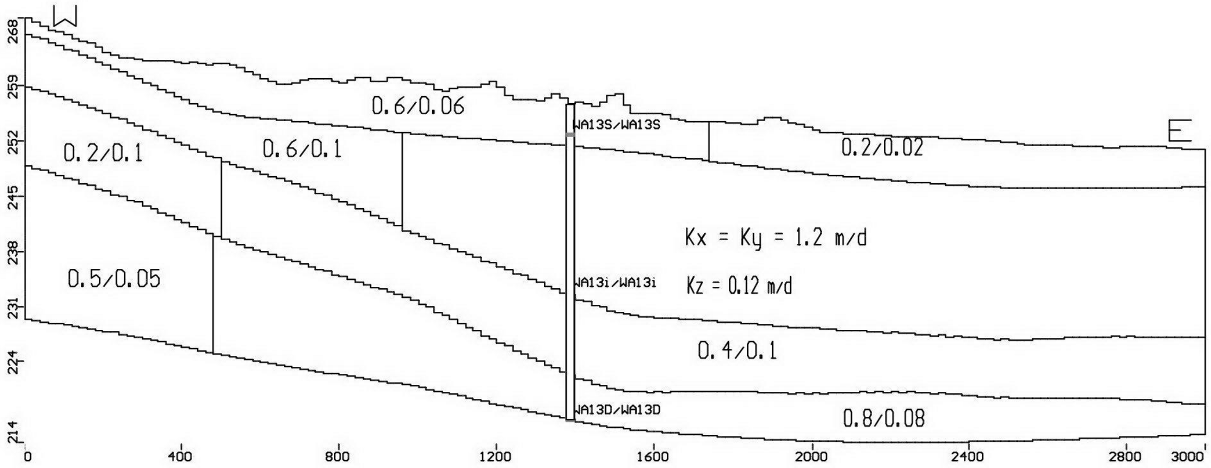

Figure 4-3. Hydraulic conductivity zones used in model calibration (horizontal value/vertical value in metres per day; axis scales are in metres) along a west-east cross-section through site 00WA13

The recharge rate required to achieve the best calibration was approximately 5.9 per cent of annual rainfall, or 25.5 mm/year, which is consistent with recharge rates estimated using hydrograph analysis (Nulsen 1998).

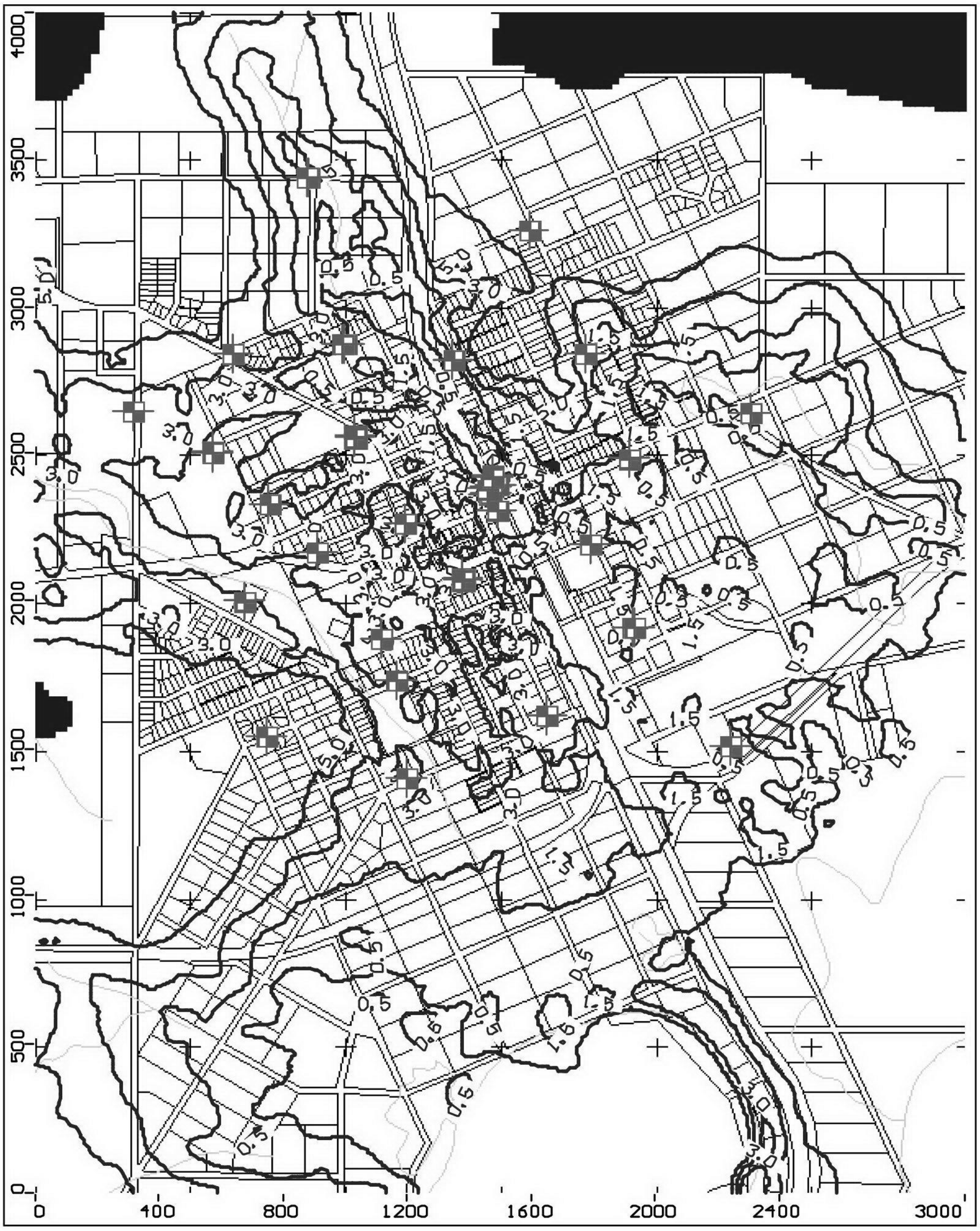

Figure 4-4. Depth to watertable for the calibrated model; the watertable was less than 0.5 m below the surface along the main drainage line and low-lying areas for the dataset used (boundary scales in metres, top of map is north)

Depths to the watertable for the calibrated model are shown in Figure 4-4 and travel paths are shown in Figure 4-5. Travel times below the townsite ranged from 400 to 500 years along the valley floor to a maximum of 1000 years from the north-eastern town catchment boundary to the outlet of the catchment in the south-eastern part of the town. These travel times are higher than those estimated for the town of Mullewa (25 to 100 years, Yesertener and Dogramaci 2000) and indicate that there is a more stagnant and less dynamic system at Wagin. This is explained by the fact that Wagin is situated predominantly in a broad flat valley and the hydraulic gradient is considerably lower than that at Mullewa.

Further evidence for the relatively slow lateral groundwater movement is seen in Figure 4-4, which shows that Wagin is characterised by a shallow watertable of 0.5 m or less below the ground level, along the low-lying areas crossing the town from north-north-west to the south-east. These salt-affected areas cover about 10 per cent of the model area between the inflow and outflow boundaries.

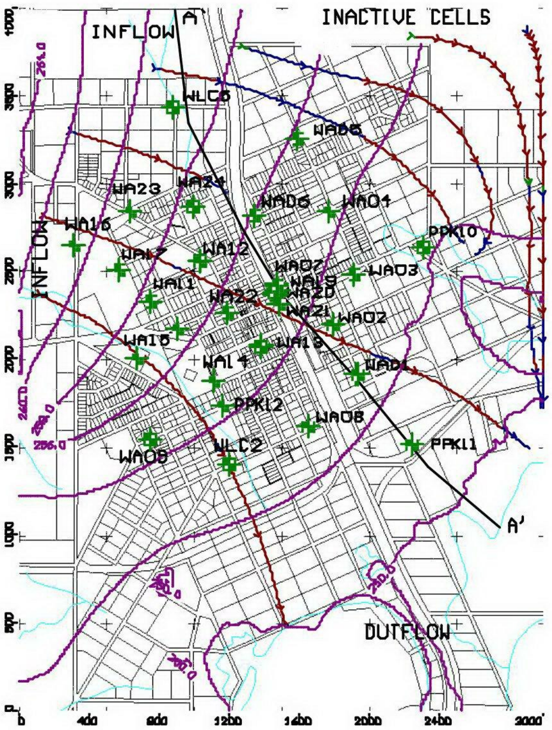

Figure 4-5. Shallow groundwater levels in metres above AHD and travel paths for the calibrated model (boundary scales in metres, top of map is north)

4.3 Dynamic simulations of strategies

The dynamic simulations extended over 30-year periods. The south-eastern general head boundary for the transient simulation was fixed over the simulation period, and it was conservatively assumed that the watertable would rise at a rate of 0.1 m/year along the north-western boundary.

4.3.1 'Do nothing differently' strategy

The 'do nothing differently' scenario implies that no management of the groundwater system will take place and, therefore, the watertable would be recharged at the average calibrated rate of 25.5 mm/year over 30 years.

Under current management practices, it was predicted that approximately 14 per cent of the active modelled area would eventually develop watertables less than 0.5 m below the ground surface in 30 years (Figure 4-6). Those areas beyond the break-of-slope and along both sides of the creekline and the natural drainage channels draining through the town to the creek would be at greatest risk.

4.3.2 Groundwater abstraction strategy

Groundwater abstraction through a bore field of 16 bores was tested in the model as a potential management option. The abstraction wells were placed only in low-lying areas where groundwater was 1 m or less from the ground surface in the modelled area. Based on the yield estimates (Table 3-2), each bore in the model was assigned a discharge rate of 50 m^3/day. Assuming that all of the modelled abstraction bores could produce such yields, and that the model was accurate, abstraction from 16 bores with the configuration shown in Figure 4-7 would be adequate to lower the groundwater level to 3 m or more below ground level beneath the low-lying areas in the 'built-up' parts of the town and towards Wagin Lake.

The temporal and spatial impact of the modelled groundwater pumping is shown in Figure 4-7. The groundwater level beneath the town fell between 1 and 3 m over 30 years.

4.3.3 Groundwater drainage strategy

Groundwater abstraction through south-east trending drains along the low-lying zones crossing through the town to Wagin Lake was also tested as a potential salinity management option (Figure 4-8). The depths of the modelled drains were 2 m and they were allocated relatively high conductance values to allow groundwater to flow freely towards them.

The impact of the drain on shallow groundwater is shown in Figure 4-8. The drain lowered the watertable to its base after 30 years. However, the effective impact of the drain was limited to only one cell width (i.e. to 20 m each side of the drain).

4.4 Conclusion

Although the model used predicted that groundwater abstraction through a bore field would be the most effective management option in controlling groundwater levels and minimising the impact of salinity, the authors recommend more comprehensive groundwater pumping tests at various sites across the town to ensure that the high sustainable yield obtained from one site can be obtained from all bores.

The pumping scenario is a very expensive option and would require pilot bores and long-term pumping tests to estimate local hydraulic parameters and evaluate sustainability of the groundwater production. The model did not take into account boundary effects during groundwater pumping. There was not enough information available to recommend long-term pumping, particularly when the landscape is criss-crossed by dykes and faults.

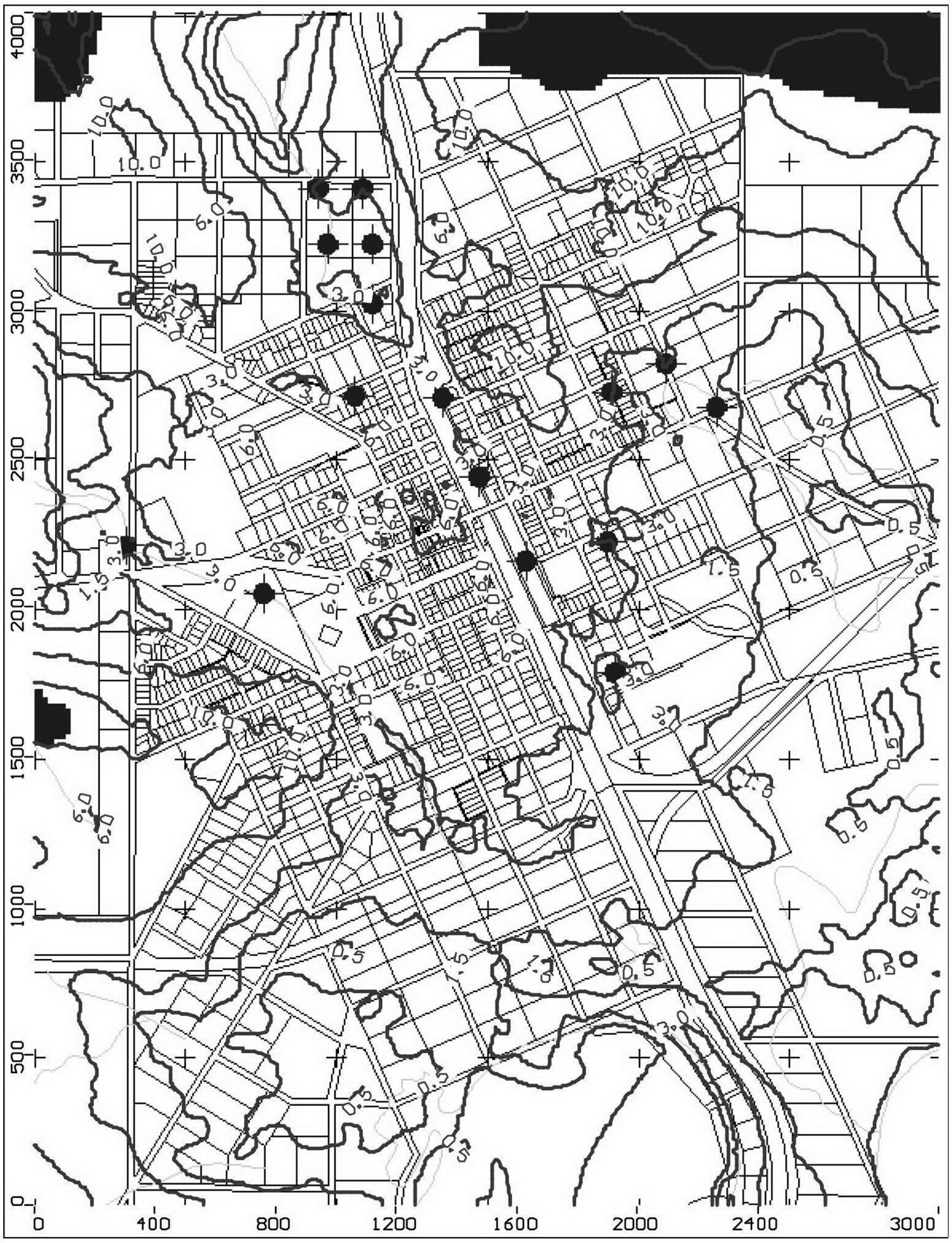

Figure 4-6. Depth to watertable (in metres) after 30 years under the 'do nothing differently' strategy (boundary scales in metres, top of map is north)

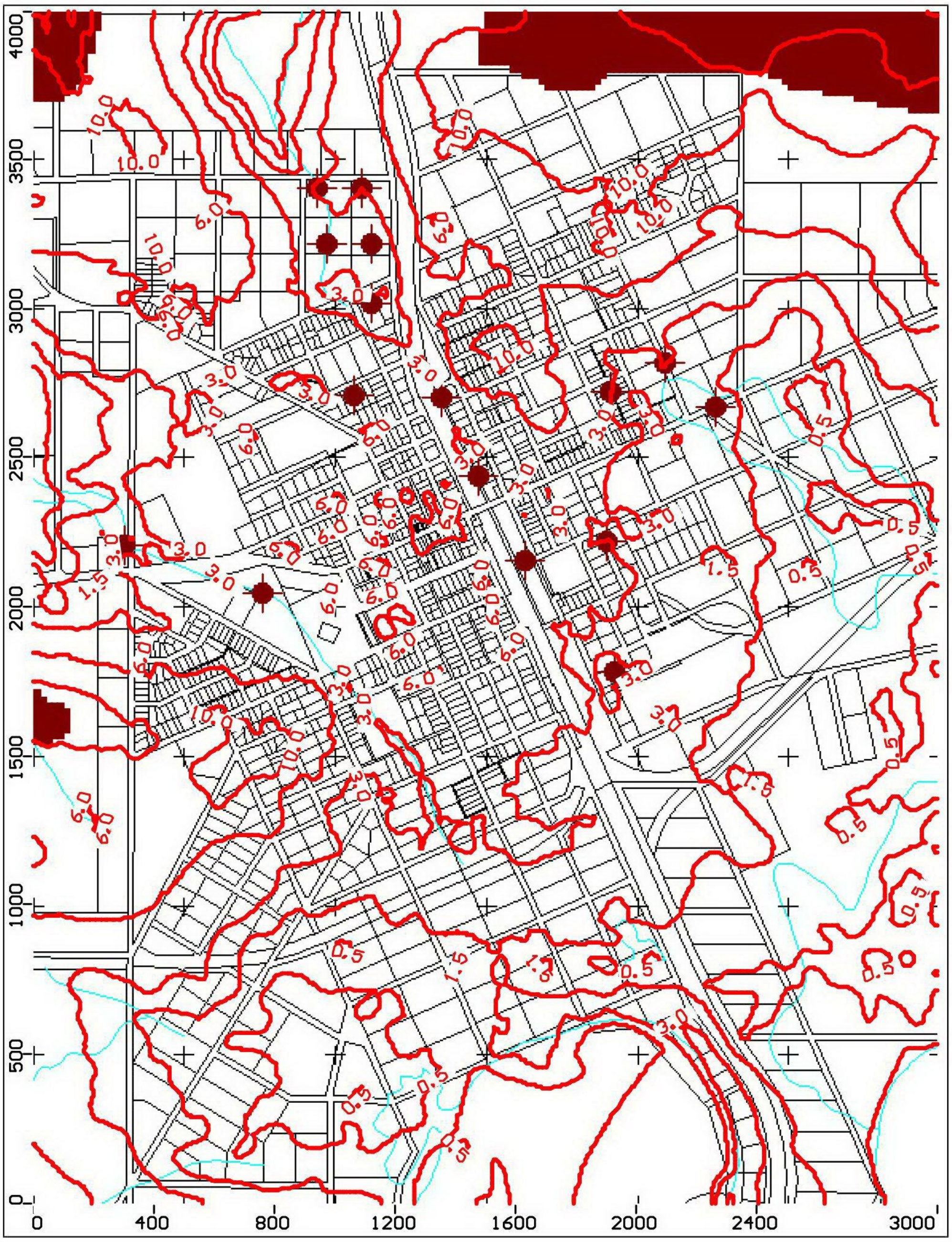

Figure 4-7. Depth to groundwater (in metres) after 30 years of pumping at 50 m^3/day from each of 16 abstraction bores (abstraction bores represented by solid crossed circles; boundary scales in metres, top of map is north)

4.5 Warning

The model results should be viewed with caution because of the assumptions used:

- The model did not account for geological structures which influence groundwater flow below the town, and the authors assumed that there was hydraulic continuity both laterally and vertically through the modelled domain, although the pattern of groundwater discharge evident in aerial photographs indicates that several features may act as barriers to groundwater flow.

- Assumptions were made about groundwater levels along the boundaries of the modelled area, although it is not known whether they are stable or rising over the long-term.
- The model results are likely to be very sensitive to both the recharge rate and values of hydraulic conductivity used, and the values used were only estimated from limited information or assumed, not measured.
- Recharge was applied evenly across all of the modelled area, but it in reality it will vary spatially.

Figure 4-8. Depth to groundwater (in metres) along the drain after 30 years (drains represented by light grey lines, boundary scales in metres, top of map is north)

5. Flood risk analysis

Author: Ali Mahtab, Catchment Hydrology Group, Agriculture Western Australia

5.1 Introduction

The issues of surface water control in Wagin were highlighted during the wet years of 1995 and 1996. Road infrastructure within the town has been badly affected by salinity and waterlogging, with concrete culverts disintegrating and road pavements failing. Many low-lying areas in the town become inundated during winter each year. The ponding is due to poor surface drainage within the town. Surface drainage is being improved using joint funding from the Rural Towns Program and the shire and is expected to reduce the flooding of the low-lying areas within the town.

5.2 Previous studies

The Soil and Water Resources Group study in 1997 concluded that control of run-off in and around the town combined with managed tree planting in the lower catchment might control salinisation in this area. It also suggested controlling run-off from the upper catchment via a series of carefully placed dams which would supply additional fresh water resources while reducing recharge in the lower catchment. The study by PKK Environment and Infrastructure Pty Ltd (2000) recommended tree planting and improving surface drainage throughout the town together with improved water-harvesting and storage in a new dam. There was no detailed investigation of the surface water hydrology and associated risk of flooding in the town in either report.

5.3 Objective of this study and approach

The objective of this part of the Community Bores Project was to assess the flood risk (high, moderate or low) of the town. This was done by calculating the peak flood flow generated by the catchments of the town (at a point just downstream of the townsite) and the volume of run-off that could be generated within the townsite, and comparing these with the flow accumulation characteristics of the catchment.

The Urban Drainage Design (UDD) model was used to calculate peak flows for the agricultural catchment because it accounts for the spatial variation in flow rates across catchments, whereas some other methods (e.g. Rational and Time-Area approaches) assume flow is uniform across catchments. The UDD model also allows precipitation rate, catchment slope, surface roughness, interception, depression storage, infiltration and evaporation to be considered. The procedures used are discussed in detail in Ali *et al*. (2001).

The catchment peak flows and the townsite run-off volumes were calculated for 1-, 6- and 24-hour rainfall storms for 2-, 5-, 10-, 20-, 50- and 100-year average recurrence intervals (ARIs) based on historical events.

5.4 Input data

The information required to run the UDD model and calculate run-off volumes was derived from available sources and from a site visit.

5.4.1 Available information

The following information was collated for the Wagin catchment:

- rainfall intensities (estimated from Institution of Engineers 1987);
- 2-metre elevation contours derived from a digital elevation model (DEM) produced by the Department of Land Administration.

A grid of the study area was derived from the DEM and this was used to predict flow directions, flow accumulations, streamlines, watershed boundaries, and slope and length of the streams. Details of the procedures used to create the grid are given in Ali *et al.* (2001).

5.4.2 On-site observations – structures influencing surface water flow

Observations made during the site visit and interpretations of aerial photographs and the elevation contours were used to derive the following:

- area of catchment (pervious and impervious);
- area generating high run-off;
- area generating high recharge;
- infiltration (maximum and minimum likely rates);
- roughness coefficient (Manning's n).

A report by Ali *et al.* (2001) contains descriptions of how the information was used in the UDD model.

It was estimated that high run-off generating areas (including roofs, roads, car parks, rock outcrops and heavy clay) covered about 20 per cent of the town area of 995 ha. A run-off coefficient of 0.9 was used for such 'impervious' areas, whereas a value of 0.1 was used for the other, 'pervious', areas.

5.5 Model calibration

To ensure that the best results are obtained using UDD modelling, the model should be calibrated using actual flow data. However, as there is no gauging station in the Wagin town catchment, parameters used for a calibrated model derived for the Moora townsite were substituted.

5.6 Results

Results are summarised in Tables 5-1 and 5-2.

Table 5-1. Peak flood flow for 2-, 5-, 10-, 20-, 50- and 100-year ARI storms for the catchment of the town of Wagin

ARI (years)	Peak flood (m^3/s)
2	1.2
5	2.1
10	7.5
20	21.0
50	29.0
100	41.0

Table 5-2. Run-off volumes for the pervious and impervious areas of the townsite generated by rainfalls of various ARIs, durations and intensities

Average recurrence interval (years)	Rainfall duration (h)	Rainfall intensity (mm/h)	Rainfall (mm)	Townsite (pervious) run-off volume (m^3)	Townsite (impervious) run-off volume (m^3)
20	1	22.00	22.00	18,000	39,000
	6	7.75	46.50	37,000	83,000
	24	3.00	72.00	57,000	129,000
50	1	30.00	30.00	24,000	54,000
	6	9.25	55.50	44,000	99,000
	24	3.75	90.00	72,000	161,000
100	1	36.00	36.00	29,000	64,000
	6	11.50	69.00	55,000	124,000
	24	4.50	108.00	86,000	193,000

5.7 *Flood risk assessment*

The criteria to classify a town's relative flood risk level were based on the calculated rates of flow, the *accumulation potential* of the townsite and the catchment above the town. The accumulation potential depends on the relative magnitudes of the potential inflows and outflows. The peak flows for the catchment for 20-, 50- and 100-year ARIs generated for storms of 24 hours duration were used to assess the flood risk within the townsite. Table 5-3 shows the flood risk to the town of Wagin for 20-, 50- and 100-year ARI storm events of 24 hours duration.

Table 5-3. Flood risk to the town of Wagin for 20-, 50- and 100-year ARI storm events of 24 hours duration

ARI (years)	Peak flow for catchment (m^3/s)	Volume of flood for urban catchment (m^3)	Accumulation risk	Flood risk	Overall flood risk
20	21	186,000	Low	Low	Low
50	29	233,000	Medium	Medium	Medium
100	41	279,000	High	High	High

5.8 Recommendation

Wagin is at overall medium risk from flooding from storm events with up to 50-year ARIs and at high risk from storms with 100-year ARIs. Localised flooding may be associated with rainfall events with ARIs greater than 20 years, with areas of low elevation mainly affected. With 50- and 100-year ARI storm events, a considerable area of the town would be affected. It is recommended that a detailed surface water management plan be developed for the townsite and contributing catchment above the town.

5.9 Warning

The input parameters, peak flows and run-off values estimated in this report should not be used as inputs for the design of any engineering structures including drains, culverts and diversion banks, as they are not suitable for this purpose. It is recommended that for any specific use the peak flow should be estimated again for the conditions existing in the catchment at that time. Detailed descriptions of the input parameters for this study and their limitations are in Ali *et al*. (2001).

6. Conclusions and recommendations

6.1 Conclusions

Of the two approaches to managing salinity, recharge reduction may have beneficial side effects, whereas groundwater pumping may have detrimental side effects. Recharge reduction measures are also likely to cost less, so it would be wise to pursue these immediately. However, an assessment of the cost of salinity to the community may indicate that groundwater pumping would have economic benefits, and so may be worthy of further investigation.

6.2 Recommendations

1. **Reduce townsite recharge.** Consider taking the steps listed Section 3.4.4.
2. **Measure groundwater levels in the monitoring network** monthly and analyse and review them annually. Continue to monitor for at least 10 years to determine whether groundwater problems are worsening and where and when most recharge occurs.
3. **Assess the current and future costs of groundwater damage in the townsite**.
4. Use the results of the second and third steps to determine whether to investigate groundwater abstraction further.
5. If groundwater abstraction is to be pursued, conduct long-term pumping tests, and use the results to model a range of pumping scenarios to determine whether pumping will be effective, and if so, determine the number and locations of required production bores and the necessary pumping rates.
6. If the fifth step indicates pumping would be effective in lowering groundwater levels below the town, assess the geotechnical impacts that groundwater abstraction will have on townsite infrastructure.
7. Assess the options for use or disposal of the pumped groundwater.
8. Determine costs of the pumping system, the costs of the damage it may cause and the costs of use or disposal of the pumped water.
9. Decide whether to go ahead with groundwater abstraction.

7. Acknowledgments

Jim Prince and Ed Solin (Agriculture Western Australia, South Perth) helped collect the information for the hydrogeological investigation and useful discussions were held with Ben Whitfield.

8. References

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Appendix 1. Pumping tests

Author: Ron Colman, Test Pumping Australia

As part of the hydrological investigation of Wagin, a pumping test was carried out in the production bore, 00WAPB1. It aimed to establish aquifer parameters.

Test Pumping Australia was contracted to carry out and analyse the pumping test.

There were two parts to the test, which were performed between 11 and 15 September 2000. The first part was a multi-rate test (that is, a series of step increases in the pump rate, with the discharge being maintained at a constant value within each step). The results of this part were assessed before setting the pump rate for the second part, which was a constant rate test.

The static water level in the bore before the multi-rate test began was 2.10 m below the reference point (which was 0.8 m above ground level). The multi-rate test was conducted on 11 September 2000 with four 30-minute steps at discharge rates of 2.0, 3.0, 4.0 and 4.3 L/s.

The constant rate test started on 12 September 2000 and lasted 4,320 minutes (72 hours) at a pumping rate of 3.5 L/s. The drawdowns in the production bore and in five deep and five shallow piezometers were measured at intervals throughout. The rates of recovery of the water levels were measured at the completion of the test.

During the tests, the flow rate was monitored using an orifice weir assembly and water levels were measured using an electric water level probe. Table A1-1 summarises relevant details.

Table A1-1: Details of the pumping test

Pump inlet depth below ground level	34 m
Available drawdown in production bore	31 m
Pump	electric submersible

A1.1 Multi-rate test

The total drawdown in the production bore at the end of the multi-rate test was 14.40 m (Figure A1-1).

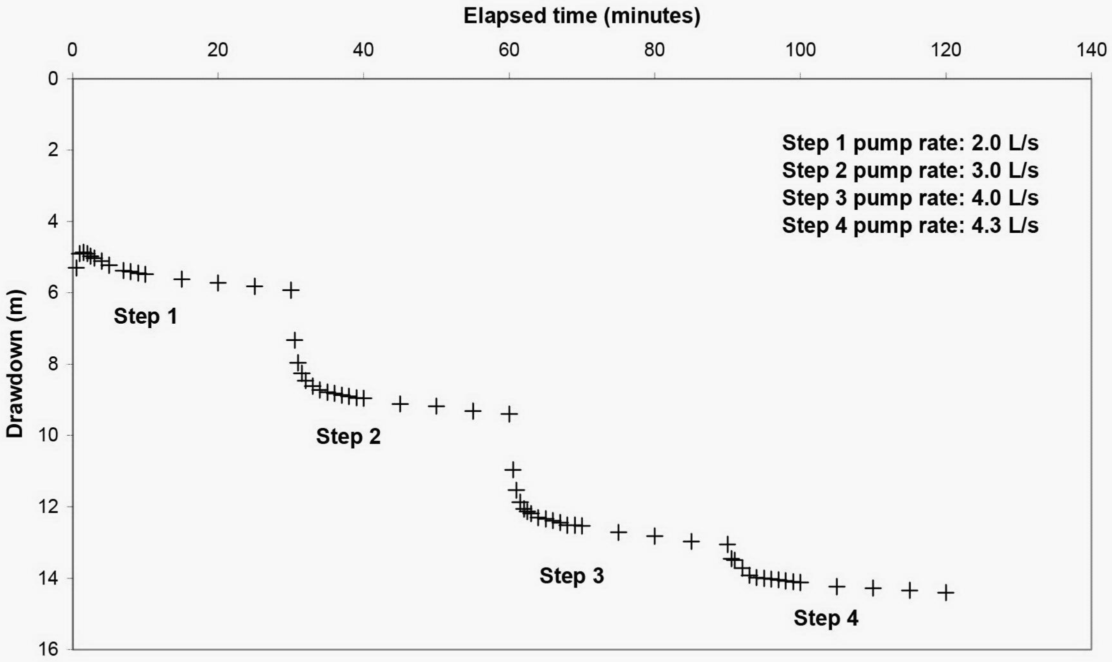

Figure A1-1: Drawdown versus time for multi-rate test

A1.2 Constant rate test

Total drawdown in the production bore at the end of the constant rate test was 15.17 m. The drawdowns in the production bore and at the monitoring sites are plotted in Figures 3-3 to 3-5 in Section 3.3.4 and details are listed in Table A1-2.

A summary of the results of the analyses is presented in Tables A1-2 and A1-3.

Table A1-2. Production bore and monitoring site details and transmissivity values (see note below) calculated for the Wagin production bore and relevant piezometers (AHD: Australian Height Datum; IR: insufficient recovery; NR: analysis not relevant)

Bore name	Intake interval elevation above AHD (m)	Lateral distance from pump (m)	Final drawdown (m)	Transmissivity (m^2/day)		
				Cooper and Jacob (time-drawdown)	Theis (curve fitting)	Theis & Jacob recovery
00WAPB1	217.4-253.4	0.1	15.17	18	25	35
00WA18D	217.6-219.6	15	5.23	25	34	30
00WA18S	251.4-253.4	15	1.01	NR	NR	NR
00WA19D	220.8-222.8	31.0	4.63	26	34	42
00WA19S	251.5-253.5	31.0	1.23	NR	NR	NR
00WA20D	222.1-224.1	30	5.26	25	33	41
00WA20S	250.7-252.7	30	2.29	NR	NR	NR
WLC4D	232.6-234.6	42.8	4.02	25	31	40
00WA07S	251.6-253.6	42.8	0.50	NR	NR	NR
00WA21D	232.3-234.3	78.2	3.30	27	33	IR
00WA21S	250.3-252.3	78.2	1.41	NR	NR	NR

Warning: The drawdown data were only analysed using computerised methods designed for homogeneous, isotropic confined and unconfined aquifers of large areal extent. Since the aquifer which was pumped does not fit these criteria, the results should only be considered as indicative. Test pumping Australia did not state whether early or late parts of the drawdown curves were used to calculate transmissivities.

Table A1-3: Summary of measurements and calculated parameters

Parameter or measurement	Results
Aquifer thickness (m)	36
Well loss	high – 55%
Electrical conductivity (mS/m)	1,320
Acidity (pH)	6.4

Note: Test Pumping Australia considered that the constant rate pumping test indicated that the bore might be capable of maintaining a long-term abstraction rate of 3.5 L/s. At this rate, they expected that there would be drawdown effects from pumping up to 500 m from the pumping bore.

Borehole 00WA01

RURAL TOWNS PROJECT

532432.68	UTM E	6313908.8	UTM N	253.218	UTM RL	UTM Grid:	AGD84

Hydrologist/Supervisor: NED CROSSLEY
Town: WAGIN
Notes/Location: Lowland flat

Date Drilled: 11/07/2000
Hole Depth (m): 40
Drill Method: AC
Hole Diameter: 125
Driller: Andrew Ferrier

From m	To m		Geology	Moisture	Water Level
0	1	<><><>	**Recent Seds** Loam sand	Moist	
1	2	<><><>	**Recent Seds** Yellow grey mottled clay. Heavy grey clay.	Moist	11/07/2000 ▼
2	3.5	<><><>	**Recent Seds** Red white mottled.	Moist	
3.5	4	:::::	**Tertiary Seds** Tight clay / ferricrete	Moist	
4	5.5	:::::	**Tertiary Seds** Sandy clay. Red and white mottles.	Moist	
5.5	7.5	:::::	**Tertiary Seds** Pale sand / clay		
7.5	9.5	:::::	**Tertiary Seds** Pale yellow / light brown clay / sand. Some cementing.		
9.5	11.5	:::::	**Tertiary Seds** Find grey clay / yellow sand.		
11.5	12.5	:::::	**Tertiary Seds** as above, tight partly cemented coarse Fe gravel to 5mm.		
12.5	14	:::::	**Tertiary Seds** Red white mottle, hard grey clay.		
14	16	:::::	**Tertiary Seds** v.hard fine grey clay, yellow gritty clay.	Damp	
16	18.5	:::::	**Tertiary Seds** Clay sand grey		
18.5	19	:::::	**Tertiary Seds** Heavy yellow gritty clay.	Moist	
19	19.5	:::::	**Tertiary Seds** Heavy fine grey clay.	Moist	

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00WA01S		4.3	0.64					
00WA01D		39.3	0.96				1.65	

Borehole 00WA01

RURAL TOWNS PROJECT

532432.68	UTM E	6313908.8	UTM N	253.218	UTM RL	UTM Grid:	AGD84

Hydrologist/Supervisor: NED CROSSLEY

Town: WAGIN

Notes/Location: Lowland flat

Date Drilled: 11/07/2000

Hole Depth (m): 40

Drill Method: AC

Hole Diameter: 125

Driller: Andrew Ferrier

19.5	21.5	░	**Tertiary Seds** Clay sand grey / yellow		
21.5	22	░	**Tertiary Seds** Fine grey clay	Moist	
22	23.5	░	**Tertiary Seds** Yellow clay sand.		
23.5	24	░	**Tertiary Seds** Yellow clay sand, red and grey mottles.	Moist	
24	26.5	░	**Tertiary Seds** fine grey sandy clay.	Moist	
26.5	29.5	░	**Tertiary Seds** Coarse grey clay sand.	Moist	
29.5	30	░	**Tertiary Seds** Coarse yellow sandy clay.	Moist	
30	32.5	░	**Pz** White clay sand	Wet	
32.5	35	░	**Pz** as above, coarse pale clay		
35	36.5	░	**Pz** Plastic fine white clay.	Wet	
36.5	38.5	░	**Sap Grit** Yellow clay sand grey and white mottles.	Damp	
38.5	39.9	░	**Sap Grit** Pale clay sand. Quartz K feldspar fragments to 8mm.		
39.9	40	+ + + +	**Wthd Granite** Weathered granite. Green K feldspar stain.		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00WA01S		4.3	0.64					
00WA01D		39.3	0.96				1.65	

Borehole 00WA02

RURAL TOWNS PROJECT

Agriculture
WESTERN AUSTRALIA

532292.42 UTM E
6314194.3 UTM N
254.13 UTM RL
UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY
Date Drilled: 11/07/2000
Town: WAGIN
Hole Depth (m): 35
Notes/Location: Lowland flat. Shire metal dump
Drill Method: AC
Hole Diameter: 125
Driller: Andrew Ferrier

From m	To m		Geology	Moisture	Water Level
0	1.2	oooooo	**Blue Metal** Blue metal from dump. Dumped by shire.		
1.2	3.5	<><><>	**Recent Seds** Yellow grey mottled heavy clay.	Moist	11/07/2000 ▼
3.5	5.5	<><><>	**Recent Seds** Red coarse sandy clay cemented in places. Soft gravel ?	Moist	
5.5	6	O--O--O--	**Fe Gravel** Ferricrete band. Pale cemented sand layer @ 5.3m.	Moist	
6	10	⁘	**Sandy Clay Ferricrete** Yellow sandy clay with fine grey mottles. Hard layer @9.3m of grey cemented sand.	Moist	
10	12	⁘	**Sandy Clay Ferricrete** Orange sandy clay with pale crème mottles. Fe gravel >10mm.	Moist	
12	16	⁘	**Sandy Clay Ferricrete** Red and white layers of clay with ferricrete layers. Hardest @ 16m.	Wet	
16	18	⁘	**Sandy Clay Ferricrete** Pale white clay with yellow / red mottles. Some partly indurated layers.		
18	19.5	⁘	**Clay** Soft white mottles in pale brown clay.		
19.5	24	⁘	**Clay** Abundant white mottled clay with some pale brown clay. Drier. Softer at 24m.		
24	27.5	⁘	**Clay** Grey white clay sand. Sandy clay with subrounded Quartz to 3mm and K feldspar to 5mm.	Wet	
27.5	31	⁘	**Pz** White gritty clay.	Moist	
31	33	⁘	**Pz** Yellow gritty clay. Quartz to 4mm.		
33	34.9	⁘	**Sap Grit** Saprolite grits. Fragments to 10mm. K feldspar to 10mm, biotite to 4mm.		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00WA02D							1.58	

Borehole	**00WA02**					**RURAL TOWNS PROJECT**	
532292.42	UTM E	6314194.3	UTM N	254.13	UTM RL	UTM Grid:	AGD84

Hydrologist/Supervisor: NED CROSSLEY
Date Drilled: 11/07/2000
Town: WAGIN
Hole Depth (m): 35
Notes/Location: Lowland flat. Shire metal dump
Drill Method: AC
Hole Diameter: 125
Driller: Andrew Ferrier

34.9	35	+ +			

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00WA02D							1.58	

Borehole **00WA03**

RURAL TOWNS PROJECT

532418.64 UTM E 6314483.3 UTM N 253.865 UTM RL UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY

Date Drilled: 12/07/2000

Town: WAGIN

Hole Depth (m): 35

Notes/Location: Footslope. Old Fire Brigade running track - Dumbleying Rd.

Drill Method: AC

Hole Diameter: 125

Driller: Andrew Ferrier

From m	***To m***		***Geology***	***Moisture***	***Water Level***
0	0.1	oooooo	**Top Soil** Yellow fine sand.	Moist	
0.1	1.1	oooooo	**Top Soil** Pale grey sand.	Moist	
1.1	2.2	<><><>	**Recent Seds** Yellow and grey mottled sandy clay (heavy).	Moist	27/07/2000 ▼
2.2	3	<><><>	**Tertiary Seds** As above, with Fe gravel -10mm.		
3	3.8	<><><>	**Tertiary Seds** Yellow bands of fine clay. Moist. Grey mottles cemented Fe gravel 4-15mm. Grey clay.	Moist	
3.8	5.5	⁙⁙⁙	**Tertiary Seds** red white mottles ferricrete layers.		
5.5	6	⁙⁙⁙	**Tertiary Seds** Grey mottles moist ->dry Ferricrete/cemented gravel nodules -30mm.	Moist	
6	7	⁙⁙⁙	**Tertiary Seds** Dark red light clay with very hard ferricrete.		
7	7.5	⁙⁙⁙	**Tertiary Seds** Hard cemented silcrete layers.		
7.5	9.5	⁙⁙⁙	**Tertiary Seds** Very hard silcrete (massive). Small pores and Fe staining. Dry.	Damp	
9.5	17.5	⁙⁙⁙	**Pz** Yellow gritty clay layer @ 17.5m. Moist @ 14m.	Moist	
17.5	18.5	⁙⁙⁙	**Pz** Very fine clay layer. Yellow.		
18.5	30.5	⁙⁙⁙	**Sap** Orange sandy clay containing sap fragmetns - 10mm. 20-24m White clay, 25-28m Coarse sand. 28-29m Quite clayey again, still gritty.		
30.5	32	⁙⁙⁙	**Sap** Very fine hard brown layer (K feldspar vein).		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m) 27/07/2000
00WA03I								1.37
00WA03D						<1		1.33

Borehole **00WA03**

RURAL TOWNS PROJECT

532418.64 UTM E 6314483.3 UTM N 253.865 UTM RL UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY

Date Drilled: 12/07/2000

Town: WAGIN

Hole Depth (m): 35

Notes/Location: Footslope. Old Fire Brigade running track - Dumbleying Rd.

Drill Method: AC

Hole Diameter: 125

Driller: Andrew Ferrier

Agriculture
WESTERN AUSTRALIA

32	35	H H H H H H H H H H H H H H H H H H H H H	**Coarse Sand Granite Frags** Coarse sand granite fragments -10mm.	

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m) 27/07/2000
00WA03I								1.37
00WA03D						<1		1.33

Borehole 00WA04

RURAL TOWNS PROJECT

532273.51 UTM E 6314834.4 UTM N 256.876 UTM RL UTM Grid: AGD84

Hydrologist/Supervisor:	NED CROSSLEY	Date Drilled:	12/07/2000
Town:	WAGIN	Hole Depth (m):	34
Notes/Location:	Lower slope. Hospital	Drill Method:	AC
		Hole Diameter:	125
		Driller:	Andrew Ferrier

From m	*To m*		*Geology*	*Moisture*	*Water Level*
0	0.2	oooooo	**Top Soil** Brown clay sand.		
0.2	2.7	<><><>	**Recent Seds** Yellow/grey mottled clay. Heavy.		
2.7	21	⋯	**Pz** Yellow @ 6m and @ 19.5m. Pallid clay fine to very fine + fine sand.		
21	23.5	⋯	**Pz** Orange, micaceous very fine light clay. Quartz fragments to 6mm @ 23m.		
23.5	24.5	⋯	**Sap Grit** Gritty sandy clay containing granite gravel to 15mm. Water @ 27m at >1L/sec.		
24.5	33.9	⋯	**Sap Grit** Coarse clay sand. K feldspar and quartz to 15mm. 27-28m gritty little clay moist coarse layer. Frags to 30mm.	Moist	
33.9	34	+ + + +	**Basement** Fragments to 10mm. Biotite rich.		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield L/s	SWL (m)	SWL 2 (m)
00WA04						>1		
00WA04						>1		

Borehole	**00WA05**			**RURAL TOWNS PROJECT**			
532095.96	UTM E	6315255.0	UTM N	263.796	UTM RL	UTM Grid:	AGD84

Agriculture
WESTERN AUSTRALIA

Hydrologist/Supervisor:	NED CROSSLEY	Date Drilled:	13/07/2000
Town:	WAGIN	Hole Depth (m):	40
Notes/Location:	Mid slope.	Drill Method:	AC
		Hole Diameter:	125
		Driller:	Andrew Ferrier

From m	*To m*		*Geology*	*Moisture*	*Water Level*
0	0.5	○○○○○○	**Grey Sand** Deposited by shire - grey sand.		
0.5	2.1	⋯	**Sandy Clay** yellow sandy clay with small grey mottles of sandy clay.		
2.1	5.2	⋯	**Sandy Clay** Red and grey mottled clay. Very fine.		13/07/2000 ▼
5.2	8.5	⁘	**Pz Wthd Granite** Weathered granite, orange clay sand fragments to 15mm, increasing to core size. 6-8.5m bioite mica.		
8.5	14	⁘	**Pz Wthd Granite** Dark yellow fine micaceous clay. Pale yellow at 11-12m, containing large chunks. Also large chunks at 13-14m. Mica biotite <1mm, very soft k feldspar to 2mm.		
14	16.2	⁘	**Pz Wthd Granite** Fine brown sandy loam. Very fine mica.		
16.2	26	⁘	**Sap Grit** Brown loam sand. Abundant mica.		
26	36.5	⁘	**Sap Grit** Brown sand becoming coarse at depth. K felspar to 3mm. Quartz to 4mm.		
36.5	39.9	⁘	**Sap Grit** Dark grey sand, almost friable K feldspar biotite to 3mm. Biotite rich, coring @ 40m. Large fragments, 50mm cores.		
39.9	40	+ + + +	**Bedrock**		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00WA05S		4.3						
00WA05D		39.3				3		

Borehole 00WA06

RURAL TOWNS PROJECT

Agriculture
WESTERN AUSTRALIA

531852.87 UTM E 6314819.9 UTM N 257.137 UTM RL UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY
Date Drilled: 13/07/2000
Town: WAGIN
Hole Depth (m): 17
Notes/Location: Very open depression
Drill Method: AC
Hole Diameter: 125
Driller: Andrew Ferrier

From m	*To m*		*Geology*	*Moisture*	*Water Level*
0	0.1	oooooo	**Loamy Sand** Loamy brown sand.		
0.1	1.1	<><><>	**Recent Seds** light brown clay sand gravel to 30mm.		
1.1	3	<><><>	**Recent Seds** Red grey mottled clay. Fe gravel to 5mm @ 2m.		22/07/2000 ▼
3	3.5	:::::	**Tertiary Seds** Dark grey clay (septic smell). Sub rounded quartz 3mm, brittle K feldspar to 3mm.		
3.5	4.5	:::::	**Tertiary Seds** Yellow (with grey mottle clay) clay sand.		
4.5	5	:::::	**Tertiary Seds** Hard cemented sand layer - silcrete.		
5	6	H H H	**Wthd Granite** Gritty yellow sandy clay. Weathered granite cores to 50mm. Micaceous.		
6	13	:::::	**Wthd Granite** Fine yellow micaceous silty clay.		
13	15	:::::	**Wthd Granite** As above gritty.		
15	16	:::::	**Wthd Granite** Fine sandy silty clay as above.		
16	16.9	:::::	**Wthd Granite** As per 13-15m, with laminar fragments to 20mm.		
16.9	17	H H H	**Biotite Rich Granite** Biotite rich granite.		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m) 22/07/2000
00WA06S		4.1						1.53
00WA06D		17.2						1.55

Borehole 00WA08

RURAL TOWNS PROJECT

532152.67 UTM E
6313615.4 UTM N
254.71 UTM RL
UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY
Town: WAGIN
Notes/Location: Lowland flat. Caravan Park

Date Drilled: 13/07/2000
Hole Depth (m): 40
Drill Method: AC
Hole Diameter: 125
Driller: Andrew Ferrier

From m	***To m***		***Geology***	***Moisture***	***Water Level***
0	0.5	oooooo	**Gravel Road Surface** Old gravel road surface.		
0.5	1	<><><>	**Recent Seds** Fine yellow clay.		
1	3	<><><>	**Recent Seds** Yellow, grey mottled heavy sandy clay.	Moist	
3	4	⋯	**Tertiary Seds** Gritty clay red and white.	Moist	
4	5	⋯	**Tertiary Seds** Fine grey clay.	Moist	
5	7	⋯	**Tertiary Seds** Red white layer, ferricrete @ 6.5m.		
7	8	⋯	**Tertiary Seds** Red clay, gritty, gravel to 20mm.		
8	11	⋯	**Tertiary Seds** Yellow clay sand, cemented @ 9.5m.		
11	14	⋯	**Tertiary Seds** More orange as 8-11m, occassional grey mottles. Orange fe nodules @ 14m.		
14	15	⋯	**Tertiary Seds** Similar colour, more clayey, still gravely. Grey clay at end of metre cemented.		
15	17.5	⋯	**Silcrete** Hard silcrete fragments to 30mm.		
17.5	18	⋯	**Pz Wthd Granite** Yellow light clay. Pallid clay, very fine containing fine sand. Off white.		
18	25	⋯	**Pz Wthd Granite** As per 17-18m. White quartz to 4mm.		
25	29.6	⋯	**Pz Wthd Granite** As per 18-25m but less quartz, almost none at 29.5m.		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00WA08S		4						
00WA08D		40.3						

Borehole 00WA08

RURAL TOWNS PROJECT

532152.67 UTM E 6313615.4 UTM N 254.71 UTM RL UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY

Town: WAGIN

Notes/Location: Lowland flat. Caravan Park

Date Drilled: 13/07/2000

Hole Depth (m): 40

Drill Method: AC

Hole Diameter: 125

Driller: Andrew Ferrier

29.6	34	⁝	**Pz Wthd Granite** Orange micaceous very fine silty clay + quartz to 5mm.		
34	39.9	⁝	**Sap Grit** Gritty sand. K feldspar to 3mm, quartz to 10mm, biotite. Slightly indurated sheared.		
39.9	40	+	Biotite rich cores. Slightly indurated sheared.		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00WA08S		4						
00WA08D		40.3						

Borehole 00WA09

RURAL TOWNS PROJECT

531250.59	UTM E	6313539.8	UTM N	264.787	UTM RL	UTM Grid:	AGD84

Hydrologist/Supervisor: NED CROSSLEY

Town: WAGIN

Notes/Location: Upland flat. BMX Track

Date Drilled: 13/07/2000

Hole Depth (m): 44

Drill Method: AC

Hole Diameter: 125

Driller: Andrew Ferrier

From m	To m		Geology	Moisture	Water Level
0	0.1	oooooo	**Top Soil** Top soil grey sandy loam.		
0.1	0.6	<><><>	**Grey Sand** Heavy grey clay.		
0.6	2.8	O--O--O--	**Mz** Grey clay including yellow mottles. Pale at times.		
2.8	4	::::::	**Pz** Cemented clay and silcrete (minor).		
4	6	::::::	**Pz** Cemented sandy clay. Pale fine clay including sand. Fe in pores and facets.		
6	9.6	::::::	**Pz** Pale cemented sandy clay.		
9.6	10.2	::::::	**Pz** Micaceous layer, yellow.		
10.2	16	::::::	**Pz** As per 6-9.6m.		13/07/2000 ▼
16	20.5	::::::	**Pz** As above but containing yellow bands. Slightly more gritty. Wet.	Wet	
20.5	25	::::::	**Pz** Greyer yellow gritty clay.		
25	26	::::::	**Sap Grit** Slightly less gritty, more micaceous.		
26	29	::::::	**Sap Grit** Grittier orange sandy clay.		
29	32	::::::	**Sap Grit** Gritty light brown sandy clay.		
32	35	::::::	**Sap Grit** Brown gritty sandy clay. Quartz and K feldspar to 4mm.		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield L/s	SWL (m)	SWL 2 (m)
00WA09						2	10.56	

Borehole 00WA09

RURAL TOWNS PROJECT

531250.59 UTM E 6313539.8 UTM N 264.787 UTM RL UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY

Date Drilled: 13/07/2000

Town: WAGIN

Hole Depth (m): 44

Notes/Location: Upland flat. BMX Track

Drill Method: AC

Hole Diameter: 125

Driller: Andrew Ferrier

35	43.5	⁙	**Sap Grit** Brown gritty clay sand. Mica - biotite, and hornblende rich.	
43.5	44	+ + + +	**Bedrock**	

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield L/s	SWL (m)	SWL 2 (m)
00WA09						2	10.56	

Borehole 00WA10

RURAL TOWNS PROJECT

531413.45	UTM E	6314168.1	UTM N	259.544	UTM RL	UTM Grid:	AGD84

Hydrologist/Supervisor: NED CROSSLEY
Town: WAGIN
Notes/Location: Lower Slope. Park opposite shire offices.

Date Drilled: 14/07/2000
Hole Depth (m): 33
Drill Method: AC
Hole Diameter: 125
Driller: Andrew Ferrier

From m	To m		Geology	Moisture	Water Level
0	0.3	oooooo	**Gravely Sand** Grey sand/gravel to 30mm.		
0.3	0.4	<><><>	**Recent Seds** Pale clay @ 1st, then heavy.		
0.4	2.8	<><><>	**Recent Seds** heavy grey clay. Fe or organic along root structures.		
2.8	3.5	⁘⁘⁘	**Tertiary Seds** Gritty yellow clay.		
3.5	6	⁘⁘⁘	**Tertiary Seds** Red gritty clay. Ferricrete and cemented sand.		14/07/2000 ▼
6	7.8	⁘⁘⁘	**Tertiary Seds** Hard dry and dusty silcrete ferricrete layer.		
7.8	10.2	⁘⁘⁘	**Tertiary Seds** Orange yellow /grey mottles sandy clay. Small gravel to 4mm. K feldspar 1-5mm.		
10.2	11.6	⁘⁘⁘	**Tertiary Seds** Grey sandy clay. Heavy. Damp.	Damp	
11.6	16.8	⁘⁘⁘	**Tertiary Seds** Red sandy clay - clay sand. Interlayers including pale white sandy clay, ferricrete, and silcrete @ 13.5m, 14.5m, and 15.5m. Very fine silcrete 50mm thick at 6.5m, Fe.		
16.8	18.2	⁘⁘⁘	**Tertiary Seds** Pale yellow containing silcrete fragments. Cemented to 30mm thick.		
18.2	19	⁘⁘⁘	**Tertiary Seds** Grey clay. Soft.		
19	20	⁘⁘⁘	**Tertiary Seds** Hard silcrete, 1m thick. Round quartz to 4mm.		
20	21	⁘⁘⁘	**Tertiary Seds** Ferricrete, apx 1m.		
21	21.5	⁘⁘⁘	**Tertiary Seds** Silcrete the softer cemented sandy clay.		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield L/s	SWL (m)	SWL 2 (m)
00WA10						1	3.77	

Borehole 00WA10

RURAL TOWNS PROJECT

Agriculture
WESTERN AUSTRALIA

531413.45 UTM E 6314168.1 UTM N 259.544 UTM RL UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY

Date Drilled: 14/07/2000

Town: WAGIN

Hole Depth (m): 33

Notes/Location: Lower Slope. Park opposite shire offices.

Drill Method: AC

Hole Diameter: 125

Driller: Andrew Ferrier

21.5	23.8	▒	**Tertiary Seds** Softer cemented clay sand.		
23.8	26.8	▒	**Tertiary Seds** Dark red ferruginous gravel. Fragments of ferricrete to 30mm. Cemented pale clay.		
26.8	27.5	▒	**Tertiary Seds** Heavy grey clay.	Moist	
27.5	28	▒	**Pz** Dark orange sandy clay containing yellow mottles. Brittle K feldspar to 7mm.	Moist	
28	29	▒	**Pz** Yellow sandy clay containing angular quartz to 5mm. K feldspar to 3mm.		
29	30	▒	**Pz** Red /grey clay mottles. Fresh K feldspar and quartz.		
30	32.9	H H H	**Sap Grit** Orange gritty clay. Quartz K feldspar to 6mm.		
32.9	33	+ + + +	**Bedrock** As above, rock fragments to 6mm. Sheared, quartz. Mostly flat chips.		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield L/s	SWL (m)	SWL 2 (m)
00WA10						1	3.77	

Borehole 00WA11

RURAL TOWNS PROJECT

531256.55 UTM E 6314329.2 UTM N 260.436 UTM RL UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY
Town: WAGIN
Notes/Location: Lower Slope. Back of bowliing greens (Nth side)

Date Drilled: 14/07/2000
Hole Depth (m): 28
Drill Method: AC
Hole Diameter: 125
Driller: Andrew Ferrier

From m	To m	Geology	Moisture	Water Level
0	0.4	**Top Soil** Grey sand.		
0.4	1.2	**Mz** Red yellow mottled clay.		
1.2	1.4	**Mz** Very tight heavy grey clay.		
1.4	3.5	**Mz** Yellow (red mottles) sandy clay. Gravel to 5mm.		
3.5	5.5	**Tertiary Seds** Dark orange sandy clay containing slightly indurated mottles.		
5.5	9	**Tertiary Seds** Red sandy clay containing grey clay mottles. Ferricrete layers.		
9	9.5	**Tertiary Seds** Yellow or brown orange slightly indurated red sandy layer.		
9.5	10.5	**Tertiary Seds** Brown as 9.5m.		
10.5	13	**Tertiary Seds** Light orange coarse sandy clay cemented grey and red sand.		
13	14	**Tertiary Seds** As 10.5-13m, but light yellow.		
14	15.5	**Tertiary Seds** Dark orange slightly indurated Fe layer @ 16m.		
15.5	17.8	**Pz Wthd Granite** Light yellow friable sandy clay containing pale tight sandy clay.		
17.8	20.2	**Pz Silcrete Ferricrete** Silcrete / ferricrete layer. Very hard.		
20.2	22	**Pz Wthd Granite** Gritty sandy clay. Pale yellow. Strongly weathered rock fragments. Biotite present to 15mm @ 23m.		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield L/s	SWL (m)	SWL 2 (m)
00WA11						<1		

Borehole 00WA11

RURAL TOWNS PROJECT

531256.55 UTM E 6314329.2 UTM N 260.436 UTM RL UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY

Date Drilled: 14/07/2000

Town: WAGIN

Hole Depth (m): 28

Notes/Location: Lower Slope. Back of bowliing greens (Nth side)

Drill Method: AC

Hole Diameter: 125

Driller: Andrew Ferrier

22	24	░	**Sap Grit** Brown clay sand. Micaceous including green sandy clay. Weathered granite.	
24	27.9	░	**Sap Grit** Coarse brown clay sand. Quartz, K feldspar, abundant biotite and mica.	
27.9	28	+		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield L/s	SWL (m)	SWL 2 (m)
00WA11						<1		

Borehole 00WA12

RURAL TOWNS PROJECT

Agriculture
WESTERN AUSTRALIA

531536.51 UTM E 6314552.7 UTM N 258.968 UTM RL UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY
Date Drilled: 14/07/2000
Town: WAGIN
Hole Depth (m): 32
Notes/Location: Lower slope.
Drill Method: AC
Hole Diameter: 125
Driller: Andrew Ferrier

From m	*To m*		*Geology*	*Moisture*	*Water Level*
0	0.2	oooooo	**Top Soil** Top soil.		
0.2	1.8	<><><>	**Sandy Clay Mottles** heavy yellow/grey mottled clay.		
1.8	5.5	∴∴∴	**Sandy Clay Ferricrete** Coarse sandy clay, yellow, containing hard sandy clay grey mottles.		
5.5	7	∴∴∴	**Sandy Clay Ferricrete** Ferricrete in coarse sandy clay as above.		
7	8.5	∴∴∴	**Sandy Clay Ferricrete** Ferricrete/silcrete yellow clay sand.		
8.5	10.5	∴∴∴	**Sandy Clay Ferricrete** Yellow clay sand including indurated yellow grey mottles.		
10.5	11.5	∴∴∴	**Sandy Clay Ferricrete** Paler yellow clay sand including soft Fe mottles.		
11.5	12.5	∴∴∴	**Sandy Clay Ferricrete** Pale yellow clay sand.		
12.5	14.5	∴∴∴	**Sandy Clay Ferricrete** Ferricrete and red sandy clay.		
14.5	16.5	∴∴∴	**Wthd Granite** Red white sandy clay including silcrete layers to 50mm.		
16.5	22.5	∴∴∴	**Pz Wthd Granite** Orange sandy clay containing gravel (ferricrete fragments) to 10mm. Soft heavy grey clay mottles.		
22.5	24	∴∴∴	**Pz Wthd Granite** Mainly grey clay as above, with some yellow sandy clay as above, ie heavier.		
24	26	∴∴∴	**Pz** Pale clay sand.		
26	29	∴∴∴	**Pz** Heavy moist grey sandy clay.	Moist	

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00WA12								

Borehole 00WA12

RURAL TOWNS PROJECT

531536.51 UTM E 6314552.7 UTM N 258.968 UTM RL UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY

Date Drilled: 14/07/2000

Town: WAGIN

Hole Depth (m): 32

Notes/Location: Lower slope.

Drill Method: AC

Hole Diameter: 125

Driller: Andrew Ferrier

29	31	⁙	**Pz** Off white clay sand.	
31	31.9	⁙	**Sap Grit** Gritty sandy clay fragments to 10mm.	
31.9	32	+	Quartz to 4mm and biotite to 3mm fragments.	

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00WA12								

Borehole	**00WA13**			**RURAL TOWNS PROJECT**			
531885.09	UTM E	6314073.7	UTM N	256.634	UTM RL	UTM Grid:	AGD84

Hydrologist/Supervisor:	NED CROSSLEY	Date Drilled:	14/07/2000
Town:	WAGIN	Hole Depth (m):	42
Notes/Location:	Footslope.	Drill Method:	AC
		Hole Diameter:	125
		Driller:	Andrew Ferrier

From m	To m	Geology	Moisture	Water Level
0	0.5	**Gravel and Sand** Deposited gravel and sand associated with carpark.		
0.5	3	**Recent Seds** Yellow sandy clay with grey clay mottles.	Moist	
3	4	**Recent Seds** Gritty yellow sandy clay containing fine yellow clay mottles.		
4	8	**Tertiary Seds** Red white duller layers. Cemented grey clay sand @ 4.5m. Red clay sand @ 5m. Ferricrete @ 7.5m. Pale white sand clay @ 5.8m.		
8	8.5	**Tertiary Seds** Orange clay sand.		
8.5	9	**Tertiary Seds** Silcrete and cemented clay sand.		
9	12.5	**Tertiary Seds** Yellow and pale yellow clay sand.		
12.5	15.5	**Tertiary Seds** Orange clay sand with grey sandy clay mottles. Indurated layers @ 15m and 16m.		
15.5	17	**Tertiary Seds** Yellow sandy clay containing heavy red and grey clay mottles. Fine grey silcrete @ 17m. Moist.	Moist	
17	19.5	**Tertiary Seds** Heavy yellow sandy clay with grey mottles. Some layers of quite plastic grey clay.		
19.5	21.5	**Tertiary Seds** Hard cemented grey and yellow clay in fine yellow clay sand. Very hard silcrete with red and yellow staining.		
21.5	23.5	**Tertiary Seds** Yellow and pale yellow clay sand interlayers some cemented grey clay and hard silcrete @ 21.5-22.7m.		
23.5	25	**Tertiary Seds** Heavy yellow sandy clay, including cemented grey sandy clay layers.		
25	26	**Tertiary Seds** Pale yellow sandy clay including soft grey clay mottles. Moist.	Moist	

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00WA13S		4						
00WA13I		30						
00WA13D		42				2		

Borehole 00WA13

RURAL TOWNS PROJECT

531885.09 UTM E | 6314073.7 UTM N | 256.634 UTM RL | UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY

Date Drilled: 14/07/2000

Town: WAGIN

Hole Depth (m): 42

Notes/Location: Footslope.

Drill Method: AC

Hole Diameter: 125

Driller: Andrew Ferrier

26	26.5	⁙	**Tertiary Seds**		
			Much more clayey. Yellow.		
26.5	29.5	⁙	**Tertiary Seds**		
			White sand. Washed round to subrounded quartz to 3mm. Some clay mottles.		
29.5	36.5	⁙	**Pz**		
			Off white clay . Coarse quartz to 5mm @ 35m. From 35m some yellow clay mottles and soft K feldspar to 3mm. Some biotite.		
36.5	39	⁙	**Pz**	Moist	
			As above but coarse sandy clay. Quartz to 8mm.		
39	40	⁙	**Wthd Granite**		
			Pale clay including yellow sandy clay (heavy) mottles. Soft K feldspar and weathered biotite present.		
40	41.9	⁙	**Wthd Granite**		
			Soft putty fine orange clay and light yellow mottles with abundant K feldspar (soft) and biotite.		
41.9	42	+ + + +	**Basement**		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00WA13S		4						
00WA13I		30						
00WA13D		42				2		

Borehole 00WA14

RURAL TOWNS PROJECT

531621.02 UTM E 6313869.9 UTM N 258.381 UTM RL UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY
Date Drilled: 18/07/2000
Town: WAGIN
Hole Depth (m): 38
Notes/Location: Footslope. School
Drill Method: AC
Hole Diameter: 125
Driller: Andrew Leeson

From m	*To m*		*Geology*	*Moisture*	*Water Level*
0	0.5	oooooo	**Top Soil** Grey loamy sand.		
0.5	1	<><><>	**Recent Seds** Yellow sandy clay.		
1	2	<><><>	**Recent Seds** Yellwo sandy clay containing grey and red mottles (soft gravel)		
2	3	<><><>	**Recent Seds** Yellow coarse sandy clay.		
3	4	······	**Tertiary Seds** Plastic grey clay. Heavy at 1st, then orange clay sand to sandy clay containing gravel to 10mm and hard grey mottles.		
4	5.5	······	**Tertiary Seds** Orange sandy clay. Hard yellow (cemented), and hard grey mottles.		
5.5	6	······	**Tertiary Seds** Red orange sandy clay containing Fe gravel to 10mm.		
6	7	······	**Tertiary Seds** Red coarse sandy clay contain Fe gravel to 20mm and off white mottled interlayer of yellow clay sand.		
7	8	······	**Tertiary Seds** As above but more off white clay mottles. Ferricrete.		
8	9	······	**Tertiary Seds** As above at 1st the white sandy clay.		
9	10	······	**Tertiary Seds** Yellow clay sand + 200mm silcrete with Fe staining in pores.		
10	11	······	**Pz** Silcrete (apx 150mm at 1st) then off white fine sandy clay.		
11	12	······	**Pz** Off white clay sand.		
12	14.5	······	**Pz** Off white fine sandy clay.		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00WA14								

Borehole	**00WA14**			**RURAL TOWNS PROJECT**			
531621.02	UTM E	6313869.9	UTM N	258.381	UTM RL	UTM Grid:	AGD84

Hydrologist/Supervisor: NED CROSSLEY

Date Drilled: 18/07/2000

Town: WAGIN

Hole Depth (m): 38

Notes/Location: Footslope. School

Drill Method: AC

Hole Diameter: 125

Driller: Andrew Leeson

14.5	15	░	**Pz** Layer of red sandy clay, then back to same as 12-14.5m.		
15	16.2	░	**Pz** As for 12-14.5m.		
16.2	19	░	**Pz** Yellow sandy clay containing pale mottles. Quartz to 4mm.		
19	21	░	**Pz Wthd Granite** Yellow sandy clay containing pale mottles. Quartz to 4mm.		
21	25	░	**Pz Wthd Granite** Yellow micaceous sandy clay. Quartz to 10mm @ 22m, then fineer to 24m where brittle K feldspar to 4mm and biotite present.		
25	28	░	**Sap Grit** Yellow micaceous sandy clay. Coarse sandy clay to 28m. Rock fragments to 8mm in yellow sandy clay with quartz and biotite. Coarse gritty layer at 28m, quartz to 8mm.		
28	38	░	**Sap Grit** Fragments to 20mm in yellow coarse sandy clay. (clay sand 35-36m).		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00WA14								

Borehole 00WA16

RURAL TOWNS PROJECT

Agriculture
WESTERN AUSTRALIA

530821.73 UTM E 6314643.1 UTM N 263.643 UTM RL UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY
Date Drilled: 18/07/2000
Town: WAGIN
Hole Depth (m): 34
Notes/Location: Lower slope. Rifle Rd.
Drill Method: AC
Hole Diameter: 125
Driller: Andrew Leeson

From m	*To m*	***Geology***	***Moisture***	***Water Level***
0	0.4	**Top Soil** Light brown sandy clay. Fine sandy clay to 0.5mm, coarse to 4mm.		18/07/2000 ▼
0.4	4.5	**Sticky fine Sandy Clay** Sticky fine sandy clay.		
4.5	6	**Pz** Heavy brown sandy clay including yellow and grey mottles.		
6	10	**Pz** Red and white sandy clay cemented Fe layer throughout. Ferricrete thick and hard @ 9.5m to 10.5m.		
10	12	**Pz** Pale clay sand containing cemented Fe/ferricrete layers.		
12	14	**Pz** Pale fine sandy clay.		
14	15	**Pz** Cemented yellow sand (round/sub round) + gritty yellow sandy clay.		
15	19.5	**Pz** Pale sandy clay quartz to 4mm. K feldspar to 4mm.		
19.5	23	**Wthd Granite** Gritty bright orange sandy clay. Quartz to 8mm, cemented very fine yellow sand. Cheesy hard coloured nodules. Paler @ 22-23m.		
23	33.9	**Sap Grit** Gritty sand 23-25m. Yellow sand pink quartz 2-5mm. 25-26m Dark grey fine sand with abundant biotite quartz to 8mm. 26-29m Pale yellow gritty sand with sheared quartz fragments to 40mm, with laminations. 30-34m pale yellow gritty sand some biotite rich la		
33.9	34	**Black Rock abt Biotite** Black rock with abundant biotite.	Wet	

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00WA16D		33.3						
00WA16S		5.6						

Borehole 00WA17

RURAL TOWNS PROJECT

Agriculture
WESTERN AUSTRALIA

531080.13 UTM E 6314504.5 UTM N 261.604 UTM RL UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY
Date Drilled: 18/07/2000
Town: WAGIN
Hole Depth (m): 23
Notes/Location: Lower slope. Show grounds.
Drill Method: AC
Hole Diameter: 125
Driller: Andrew Leeson

From m	To m		Geology	Moisture	Water Level
0	1	oooooo	**Sandy Clay** Brown sandy clay.		
1	3	<><><>	**Heavy Sandy Clay** Heavy light brown sandy clay.		
3	7	∴∴∴	**Clay Sand** Red brown sandy clay with yellow mottles. Some cemented layers to 6.5m.		
7	9	∴∴∴	**Clay Sand Quartz Floaters** Cemented fine yellow and grey sand in pale yellow clay sand. Orange mottles.		
9	10	∴∴∴	**Clay Sand Quartz Floaters** Weathered granite fragments to 8mm in dark grey gritty sandy clay.		
10	11.5	∴∴∴	**Clay Sand Quartz Floaters** Gritty pale yellow and pale pink sandy clay. Quatz to 40mm. Cemented clay @ 11m.		
11.5	13	∴∴∴	**Pz** Large quartz fragments in pale brown clay and white clay. Quartz to 40mm.		
13	15.5	∴∴∴	**Pz** Palid clay containing quartz to 10mm. (Plastic off white clay).		
15.5	17.5	∴∴∴	**Pz** Dark orange gritty clay. Soft K feldspar to 5mm.		
17.5	20	∴∴∴	**Sap Grit** Pale brown gritty clay with abundant quartz fragments to 25mm.		
20	22.9	∴∴∴	**Sap Grit** Brown clay but mostly quartz fragments to 50mm.		
22.9	23	+ + + +	**Quartz Basement**		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00WA17								

Borehole 00WA18

RURAL TOWNS PROJECT

Agriculture
WESTERN AUSTRALIA

531973.72 UTM E 6314387.9 UTM N 255.251 UTM RL UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY

Date Drilled: 21/07/2000

Town: WAGIN

Hole Depth (m): 38

Notes/Location: Footslope. Palace car park.

Drill Method: AC

Hole Diameter: 125

Driller: Andrew Leeson

From m	To m	Geology	Moisture	Water Level
0	0.2	**Sand** Grey sand.		
0.2	1.8	**Recent Seds** Heavy yellow sandy clay containing heavy grey mottles.		
1.8	3	**Tertiary Seds** Red sandy clay containing heavy grey clay mottles.		
3	6	**Tertiary Seds** Red/white sandy clay containing coarse sand and layers of cemented grey clay sand and ferricrete @ 6m.		
6	10	**Tertiary Seds** Yellow clay sand cemented layers. Silcrete @ 9.5m.		
10	11	**Tertiary Seds** Yellow sandy clay containing grey mottles (heavy clay).		
11	13	**Sap Grit** Yellow gritty clay containing pale rock fragments to 13mm (brittle). K feldspar soft.		
13	14.5	**Sap Grit** Brown clay sand with abundant mica.		
14.5	15	**Sap Grit** As for 11-12m.		
15	19.5	**Sap Grit** Mica rich gritty clay sand. Very gritty 17-18m. Dark grey @ 16-17m.		
19.5	20	**Sap Grit** Cheesy colour nodules containing brittle K feldspar to 4mm in light brown gritty sand. Very fine plastic clay layer at 19.5m.		
20	24	**Sap Grit** Clay sand, gritty quartz and K feldspar to 10mm.		
24	37.9	**Sap Grit** Gritty sand pale yellow. Quartz and biotite present.		
37.9	38	**Qtz Kspar Biotite**		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00WA18								

Borehole 00WA19

RURAL TOWNS PROJECT

531988.38	UTM E	6314395.1	UTM N	255.197	UTM RL	UTM Grid:	AGD84

Hydrologist/Supervisor:	NED CROSSLEY	Date Drilled:	21/07/2000
Town:	WAGIN	Hole Depth (m):	35
Notes/Location:	Footslope. Palace Car park no.2	Drill Method:	AC
		Hole Diameter:	125
		Driller:	Andrew Leeson

From m	To m		Geology	Moisture	Water Level
0	3	<><><>			
3	4	<><><>	**Ferricrete** Ferricrete		21/07/2000 ▼
4	5	░	**Sandy Clay** Grey sand		
5	5.9	░	**Sandy Clay** Grey/red sandy clay.		
5.9	6	░	**Sandy Clay** Hard silcrete.		
6	11	░	**Sandy Clay** Yellow sand clay. Fe gravel @ 9m. Minor silcrete @ 11m.		
11	14	░	**Sap Grit** Micaceous clay sand weathered fragments to 10mm.		
14	24.5	░	**Sap Grit** Dark olive grey. Hard layers.		
24.5	29.5	░	**Sand** Yellow gritty sand.		
29.5	30.5	░	**Sand** Dark grey sand.		
30.5	34.9	░	**Sand** Dark grey sand. Hard layer 32-33m.		
34.9	35	░	**hard Layer**		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00WA19								

Borehole 00WA21

RURAL TOWNS PROJECT

531991.40 UTM E 6314309.6 UTM N 255.865 UTM RL UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY
Town: WAGIN
Notes/Location: Footslope. Railway crossing

Date Drilled: 21/07/2000
Hole Depth (m): 25
Drill Method: AC
Hole Diameter: 125
Driller: Andrew Leeson

From m	To m		Geology	Moisture	Water Level
0	0.5	○	**Sand Loam** Grey sand loam.		
0.5	1.5	⁙	**Tertiary Seds** Dark grey clay		
1.5	2.5	⁙	**Tertiary Seds** Yellow grey sandy clay. Moist.	Moist	
2.5	3	⁙	**Tertiary Seds** Grey sandy clay containing yellow mottles.		
3	5.5	⁙	**Tertiary Seds** Red and yellow sandy clay containing hard grey clay layers.		
5.5	6.5	⁙	**Tertiary Seds** Ferricrete		
6.5	7.5	⁙	**Tertiary Seds** Grey clay sand		
7.5	8.5	⁙	**Tertiary Seds** Red sandy clay.		
8.5	11.5	⁙	**Tertiary Seds** Yellow sandy clay partly indurated @ 8.5m, 9.5m. Soft plastic interlayers throughout.		
11.5	15	⁙	**Pz Wthd Granite** Brown layer at 13.5-14.5m with fine plastic white clay. Partly indurated @ 15.5m.		
15	16	⁙	**Pz Sandy Clay** Red indurated ferricrete.		
16	18	⁙	**Sap Grit** Gritty sandy clay yellow and white with K feldspar (soft to 8mm).		
18	19	⁙	**Sap Grit** Very gritty sandy clay brown.		
19	24.9	⁙	**Sap Grit** Very gritty sandy clay. Brown. K feldspar to 8mm, hard. Little mica.		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00WA21								

Borehole 00WA21

RURAL TOWNS PROJECT

531991.40 UTM E 6314309.6 UTM N 255.865 UTM RL UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY

Date Drilled: 21/07/2000

Town: WAGIN

Hole Depth (m): 25

Notes/Location: Footslope. Railway crossing

Drill Method: AC

Hole Diameter: 125

Driller: Andrew Leeson

24.9	25	▒	**Sap Grit**		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00WA21								

Borehole 00WA22

RURAL TOWNS PROJECT

531693.61 UTM E
6314260.7 UTM N
257.909 UTM RL
UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY
Date Drilled: 24/07/2000
Town: WAGIN
Hole Depth (m): 37.5
Notes/Location: Footslope and lower flat. Library.
Drill Method: AC
Hole Diameter: 125
Driller: Andrew Leeson

From m	To m	Geology	Moisture	Water Level
0	0.2	**Road Base** Road base. Bitumen.		
0.2	2	**Clay** Heavy grey clay mottles.		
2	3.5	**Clay** Yellow sandy clay containing heavy grey clay mottles.		
3.5	6	**Clay** Red yellow sandy clay - clay sand containing grey mottles. Ferricrete/silcrete @ 4.5m (brittle). Pale clay sand @ 5.5m.		
6	8.5	**Clay** Red and white fine sandy clay.		
8.5	11	**Tertiary Seds** Fine pale clay sand interlayers indurated. Ferri/silcrete @ 8.5m.		
11	13	**Tertiary Seds** Dark yellow fine clay sand to sandy clay containing K feldspar and rounded quartz to 3mm, silcrete, and cemented fine sand.		
13	15.5	**Pz Wthd Granite** Softer red and white sandy clay containing soft pale grey clay mottles, and minor indurated and cemented layers.		
15.5	15.6	**Pz Wthd Granite** Hard dusty white layer.		
15.6	19	**Pz Wthd Granite** Grey sandy clay. Soft plastic yellow and white clay @ 18-18.3m.		
19	20.5	**Pz Wthd Granite** Yellow and white sandy clay.		
20.5	22.5	**Pz Wthd Granite** Red grey sandy clay. Slightly indurated Fe nodules.		
22.5	23	**Pz Sandy Clay** Grey clay sand some cemented @ 22.5m.		
23	24	**Pz Sandy Clay** Yellow and pale grey heavy sandy clay (plastic) round quartz to 5mm.		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield L/s	SWL (m)	SWL 2 (m)
00WA22D		37.7				<1		
00WA22S		4.2						

Borehole 00WA22

RURAL TOWNS PROJECT

531693.61 UTM E 6314260.7 UTM N 257.909 UTM RL UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY

Date Drilled: 24/07/2000

Town: WAGIN

Hole Depth (m): 37.5

Notes/Location: Footslope and lower flat. Library.

Drill Method: AC

Hole Diameter: 125

Driller: Andrew Leeson

24	25.5	⁙	**Pz Sandy Clay**	Orange and yellow sandy clay with tight heavy grey sand clay mottles.
25.5	26	⁙	**Pz Sandy Clay**	Heavy grey clay.
26	29	⁙	**Pz Sandy Clay**	Coarse sandy clay, grey, containing yellow layers K feldspar and round quartz to 5mm present.
29	30	⁙	**Pz Sandy Clay**	Pale sandy clay (finer sand) subrounded quartz to 5mm still present.
30	31	⁙	**Pz Sandy Clay**	Pale sandy clay.
31	32	⁙	**Pz Sandy Clay**	Grey and yellow sandy clay in situ weathered granite (soft K feldspar to 4mm).
32	35.5	H H H	**Sap Grit**	Grey sand abundant biotite and K feldspar to 5mm. Quartz to 8mm.
35.5	38.4	H H H	**Sap Grit**	Fresh K feldspar rock fragment to 15mm.
38.4	38.5	+ + + +	**Basement**	

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield L/s	SWL (m)	SWL 2 (m)
00WA22D		37.7				<1		
00WA22S		4.2						

Borehole	**00WA23**			**RURAL TOWNS PROJECT**			
531143.05	UTM E	6314836.1	UTM N	262.494	UTM RL	UTM Grid:	AGD84

Hydrologist/Supervisor:	NED CROSSLEY	Date Drilled:	24/07/2000
Town:	WAGIN	Hole Depth (m):	38
Notes/Location:	Lower slope	Drill Method:	AC
		Hole Diameter:	125
		Driller:	Andrew Leeson

Agriculture
WESTERN AUSTRALIA

From m	To m		Geology	Moisture	Water Level
0	0.5	<><><>	**Gravel and Sand** Yellow gravely sand. Fe gravel to 10mm.		
0.5	2.2	<><><>	**Gravel and Sand** Yellow brown gravely clay. Small gravel 1-2m.		
2.2	4.5	⋯	**Sandy Clay** Brown red containing yellow mottles. Sandy clay. Some gravel. Dark brown.red fine sandy clay.		
4.5	5.5	⋯	**Sandy Clay** Pale sandy clay.		
5.5	6	⋯	**Silcrete** Silcrete cemented clay. Very hard.		
6	6.5	⋯	**Silcrete** Soft plastic white sandy clay. Micaceous.		
6.5	7.1	⋯	**Silcrete** Gritty sandy clay. Brown.		
7.1	9	⋯	**Silcrete** Orange to red brown sandy clay. Micaceous.		
9	14	⋯	**Pz Sandy Clay** yellow sandy clay. Micaceous.		
14	19	⋯	**Sap Grit** Light brown micaeceous gritty sandy clay. Increasing in grit size to 12mm.		
19	22	⋯	**Coarse Sand** Brown biotite and mica present. Rock fragments to 12mm.		24/07/2000 ▼
22	26	⋯	**Coarse Sand** Coarse sand mica biotite.		
36	37.9	⋯	**Coarse Sand** As 22-26m. K felspar present. Rock fragments from 33m to 15mm.		
37.9	38	+ + + +			

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00WA23D		36.2					22	
00WA23S		4.2						

Borehole 00WA24

RURAL TOWNS PROJECT

531500.24 UTM E 6314866.4 UTM N 258.811 UTM RL UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY

Date Drilled: 24/07/2000

Town: WAGIN

Hole Depth (m): 38

Notes/Location: Lower slope

Drill Method: AC

Hole Diameter: 125

Driller: Andrew Leeson

From m	To m		Geology	Moisture	Water Level
0	0.5	oooooo	**Sandy Loam Gravel** Dark brown sandy loam gravel.		
0.5	2.5	<><><>	**Clay** Heavy yellow light brown clay.		
2.5	3.5	∷	**Mz Sandy Clay** Yellow sandy clay containing heavy sandy clay grey mottles.		
3.5	4.5	∷	**Mz Sandy Clay** Red sandy clay with subrounded quartz to 8mm. Indurated @ 3.9-4.2m.		
4.5	5.5	∷	**Mz Sandy Clay** Grey sandy clay.		
5.5	6.5	∷	**Ferricrete** Silcrete in red sandy clay.		
6.5	7.5	∷	**Pz Sandy Clay** Light grey sand clay containing Fe indurated gravel.		
7.5	8.5	∷	**Pz Sandy Clay** Orange sandy clay containing hard clay and indurated gravel layers.		
8.5	10	∷	**Pz** Dark yellow sandy clay containing off white layers of fine clay.		
10	13	∷	**Pz** White and red layers of sandy clay interlayered with tight pale grey to off white clay and indurated (ferricrete) chips to 20mm.		
13	14.5	∷	**Pz** Pale yellow sandy clay layers of pale grey sandy clay.		
14.5	15.5	∷	**Pz** Ferricrete with indurated fragments to 40mm in red and yellow sandy clay.		
15.5	16.5	∷	**Pz** Tight grey sandy clay in grey sandy clay.		
16.5	19.5	∷	**Pz** Grey sandy clay.		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield L/s	SWL (m)	SWL 2 (m)
00WA24D		38				<2		
00WA24S		4						

Borehole 00WA24

RURAL TOWNS PROJECT

531500.24 UTM E 6314866.4 UTM N 258.811 UTM RL UTM Grid: AGD84

Hydrologist/Supervisor: NED CROSSLEY

Town: WAGIN

Notes/Location: Lower slope

Date Drilled: 24/07/2000

Hole Depth (m): 38

Drill Method: AC

Hole Diameter: 125

Driller: Andrew Leeson

19.5	23.5	⁙	**Pz** Grey clay sand.		
23.5	25.5	⁙	**Pz** Grey sandy clay.		
25.5	26.5	⁙	**Sap Grit** Tight olive grey clay containing abundant weathered K feldspar.		
26.5	29	⁙	**Sap Grit** Yellow gritty clay with friable olive grey weathered K feldspar.		
29	30	⁙	**Clay Sand** As for 26.5 to 29m. Mica present.		
30	31	⁙	**Clay Sand** Brown clay sand with abundant biotite mica.		
31	37.9	⁙	**Clay Sand** Gritty sand. Yellow. Flat chips. Sheared horizontally.		
37.9	38	+	**Sheared Horizontally**		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield L/s	SWL (m)	SWL 2 (m)
00WA24D		38				<2		
00WA24S		4						