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Groundwater study of the Bencubbin townsite

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Groundwater study of the Bencubbin townsite

Fay Lewis

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Disclaimer

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

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Summary

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

Twelve piezometers were installed at nine sites. Bedrock was struck at eight of the sites drilled between 4 and 35 m deep. Depth to bedrock increased downslope. The bedrock was granitoid at all eight sites at which it was struck, although mafic dykes were identified from surface features in the surrounding area. The regolith was predominantly residual clays, overlain at some sites by colluvium.

At most sites, the watertable was greater than 7 m below ground level. At the site with the shallowest bedrock (4 m deep), the piezometer was dry when monitored on four occasions between July and October 2000. However, on 12 December 2000, there was a watertable at only 2.4 m below ground level. The water levels in several other piezometers also rose between October and December 2000. There was little rainfall during this period, and the cause of the rise is unknown.

The available groundwater records are short so it is not clear whether groundwater levels are rising, or where and when most groundwater recharge occurs.

The flood risk assessment for the town concluded that the risk was low, although localised flooding could occur following heavy rainfall events.

There are opportunities to reduce townsite recharge immediately, and some of these would have additional benefits. It was recommended that such opportunities be taken and that groundwater levels are measured frequently and regularly over the long-term so that the risk of salinity can be assessed and the important recharge zones can be identified.

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1. Introduction and background information

Authors: Peter Lacey and Shahram Sharafi (Agriculture Western Australia) and Cahit Yesertener and Shawan Dogramaci (Water and Rivers Commission)

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

For Bencubbin, the groundwater study consisted of a drilling program, establishment of a piezometer network, groundwater flow modelling and a flood risk analysis. This report documents the background information for the town and its catchment (Sections 1.1 to 1.4) and the hydrogeological and flood risk investigations (Sections 2 to 4) and then recommends steps for managing the town's salinity risk effectively (Section 5).

Bencubbin (latitude: 30^{o}48'S; longitude: 117^{o}52'E) is 285 km north-east of Perth (Figure 1-1). Rising groundwater is of concern to the town's residents; water in the cellar of the hotel is thought to be caused by a shallow watertable less than 3 m below ground level (VORAN 1999).

1.1 Description of the catchment

Bencubbin is about 5 km west of the broad flat valley floor of a major (but unnamed) north-to-south drainage system (Figure 1-1). The town is sited on the south-western slopes of a spur separating two subcatchments of the main catchment (Figure 1-2). All watercourses are ephemeral.

The landform pattern is undulating and the average slope in the town's catchment is 2.5 per cent. The town is elevated (about 16 m) above the main watercourse of the catchment in which it is sited (Figure 1-2).

1.2 Geology

Blight *et al*. (1984) mapped biotite granitoid bedrock below the spur on which Bencubbin is sited. They also identified several quartz and mafic dykes trending north-north-east to east-north-east in the surrounding area. They noted that these intrusions were emplaced into fractures and possibly faults.

Tertiary weathered profiles containing laterite and/or silcrete and Tertiary sandplain deposits hide the bedrock across most of the area near the town (Blight *et al*. 1984).

Several exposures of granitoid around the townsite indicate that the regolith may be shallow below some sites. Aerial photographs show prominent linear features, predominantly running west to east. There are also less prominent lineaments running in other directions (for example, a short one strikes north-eastwards towards the townsite on its western side). These features were interpreted as mafic dykes.

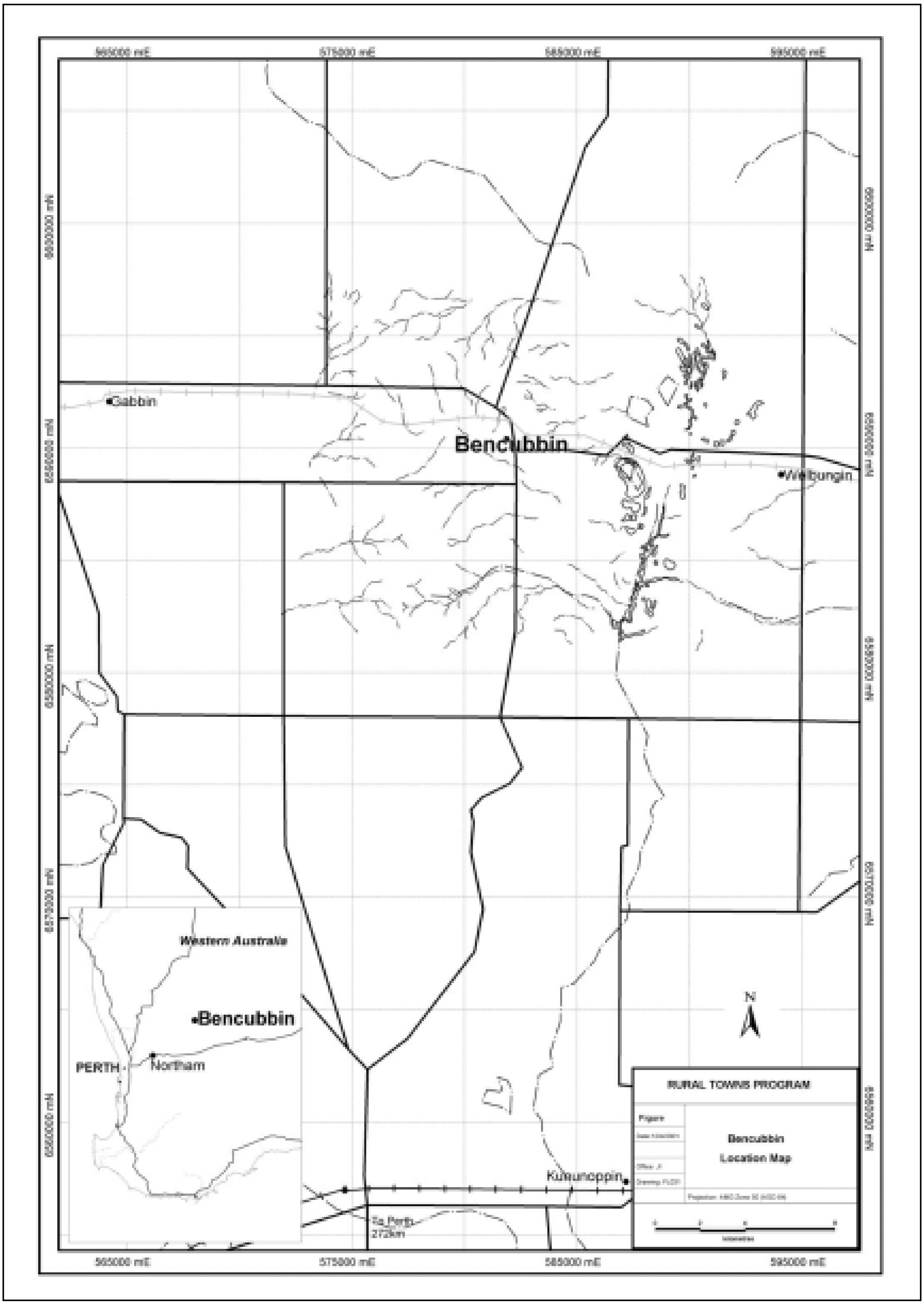

Figure 1-1. Regional setting of Bencubbin townsite

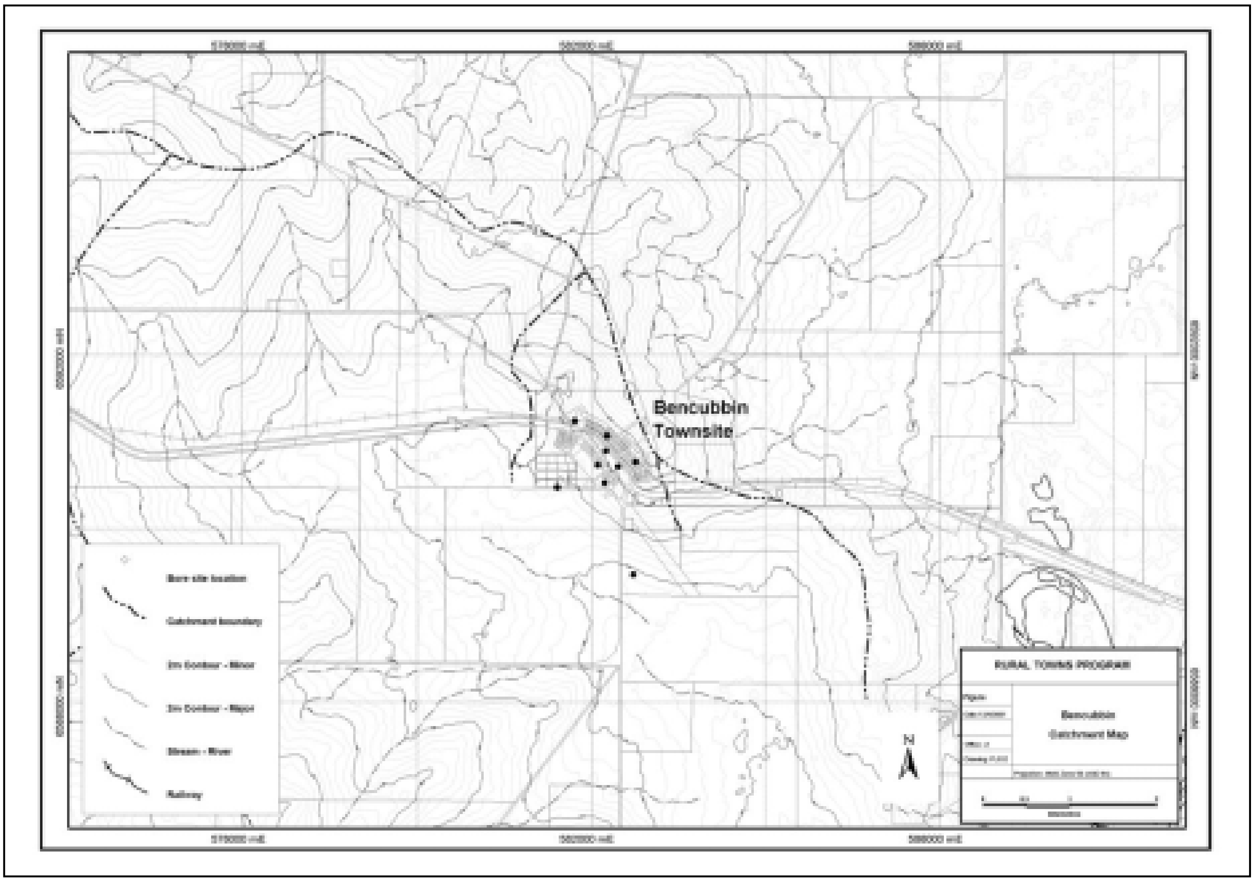

Figure 1-2. Location of the Bencubbin townsite in its catchment

1.3 Climate

The area has hot dry summers and cool wet winters. Mean annual rainfall for Bencubbin is 321 mm (Bureau of Meteorology 2000). Over the long-term, 70 per cent of rain falls from May to October, however, during summer, high intensity rainfall events result from cyclonic activities.

1.4 Hydrogeology

The groundwater systems below Bencubbin have not previously been investigated. George and Frantom (1990) installed a series of piezometers about 10 to 15 km south-east, in valley floor, lower and mid-slope locations east of the main north-south drainage line (see Section 1.1). They called the subcatchment the ‘Welbungin Catchment’. As they did not investigate upper slope locations with shallow bedrock similar to the Bencubbin site, applicability of their results is limited. The piezometers installed in mid-slope locations were not deep enough to tap the watertable (7 to 17 m below ground). They presented a cross-section that indicated the watertable was about 40 m deep below a mid-slope site monitored by the Geological Survey of Western Australia. The watertable below the main valley floor was close to ground level and associated with land salinisation. George and Frantom thought that hydraulic gradients were low and that this implied a "lack of significant recharge".

2. Hydrogeology investigation

Authors: Peter Lacey (Agriculture Western Australia) and Fay Lewis (Fay Lewis Consulting)

The hydrogeology investigation aimed to determine which salinity prevention options would be most effective in Bencubbin. The investigation consisted of a drilling program coupled with the installation of a groundwater monitoring network. The methods used, the results and the interpretations of the results are described in Sections 2.1 to 2.3, and management options are discussed in Section 2.4.

2.1 Method

Drilling for the Community Bores Project was carried out on 4 and 5 July 2000. Twelve piezometers were installed at nine sites (00BN01 to 00BN09, Figure 2-1). Note that in some Agriculture Western Australia records piezometer 00BN01D has also been called 00BN01I and piezometer 00BN09I has also been called 00BN09S. A production bore was not installed as flow rates at all piezometer sites were estimated to be low.

2.1.1 Drill site selection

Drill site selection was based on land availability and access and suitable spacing of monitoring sites.

2.1.2 Drilling methods

LA Boyle Pty Ltd were contracted to drill the chosen sites and install piezometers. Most sites were drilled using reverse circulation methods with a 125 mm-diameter bit.

2.1.3 Piezometer construction

In all piezometers, 50 mm-diameter class 9 PVC casing was installed. Two-metre lengths of slotted casing with 1 mm-aperture slots were positioned at the bottom of each hole and the remainder was 'plain cased'. The annuluses were packed with 1.6 to 3.2 mm-diameter washed graded gravel around the slotted sections and sealed using 1 m-long bentonite plugs, and then the remaining annulus of each hole was packed with drill chips. Details are listed in Table 2-1.

2.1.4 Drill sample analyses

One bulk sample was taken per meter from each bore. Descriptive logs were recorded and are available at <http://www.agric.wa.gov.au/environment/links/RMtechreports/>.

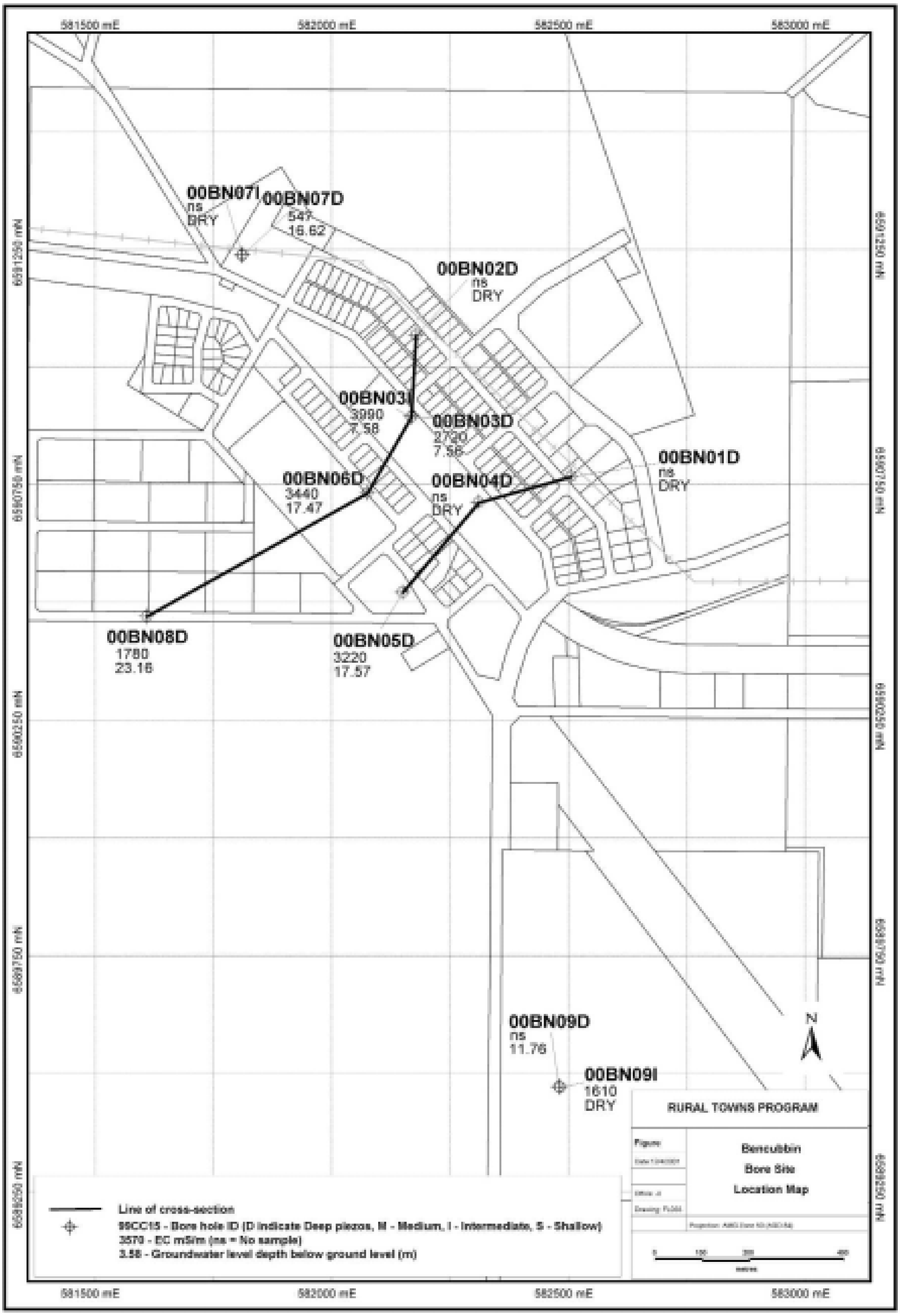

Figure 2-1. Piezometer sites, groundwater level depths (in metres) and

electrical conductivity values (in milliSiemens per metre) from piezometers on 12 September 2000, and locations of cross-sections in Figures 2-2 and 2-3

2.1.5 Groundwater monitoring and sample analyses

Groundwater levels were measured and samples were taken every month to October 2000 by Agriculture Western Australia. The measurement interval was then increased to three months. Electrical conductivity (EC) values of the water samples were measured at Agriculture Western Australia laboratories in South Perth. Results are stored on the Agriculture Western Australia AgBores database.

2.1.6 Surveying

Locations (eastings and northings) and elevations of piezometers were surveyed using a differential global positioning system (GPS) which was accurate to about ±20 mm horizontally and ±50 mm vertically.

2.2 Results

2.2.1 Profile descriptions

Detailed drill logs are available at <http://www.agric.wa.gov.au/environment/links/RMtechreports/> and the main components of the profiles are illustrated in Figures 2-2 and 2-3.

Bedrock was struck at eight of the sites drilled (00BN01 to 00BN08) between 4 and 35 m deep. The elevation of the bedrock surface at those sites ranged from 339 to 355 m above Australian Height Datum (AHD). Bedrock was particularly shallow at sites 00BN01 and 00BN02 (7 and 4 m below ground level) and it was also highest at these two locations (355 and 354 m above AHD). Depth to bedrock increased downslope. The hole at site 00BN09 was drilled to 50 m but bedrock was not reached. The bedrock was granitoid at all eight sites at which it was found, although aerial photographs show prominent linear features which were interpreted as mafic dykes, crossing the townsite and surrounds, mostly from west to east.

The regolith at most sites was predominantly residuum of mottled and pallid zone clays overlying a weathering rock zone (Figures 2-2 and 2-3). Colluvial clays, sands and gravels were several metres thick at three sites (00BN03, 00BN08 (Figure 2-3) and 00BN09).

2.2.2 Groundwater levels

Table 2-1 lists the groundwater level depths in the piezometers when measured on three dates between July and December 2000, and Figure 2-1 illustrates how they varied across the townsite on 21 September 2000.

Groundwater levels were measured five times between July and December 2000. Three piezometers were dry each time (00BN01D, 00BN07I and 00BN9I). Piezometers 00BN02D (about 4 m deep) and 00BN04D (about 15 m deep) contained water in December 2000 although they had been dry when measured in

September and October 2000. The height of the column of water was about 1.7 m in piezometer 00BN02D, and at least 1 m in piezometer 00BN04D. (Site 00BN02D is near the hotel, the cellar of which is known to have water seepage problems.) However, groundwater levels at sites 00BN05, 00BN06, 00BN07 and 00BN08 were also at their highest when read in December, but piezometers 00BN03D and 00BN09D had lower levels in December then earlier in the year.

At those sites with water in the piezometers, the depths were greater than 7 m below ground level on all occasions, except at site 00BN02D in December, when the groundwater was only 2.4 m below ground.

(*Note that the groundwater level depths are recorded in the Agriculture Western Australia AgBores database as depths below ground level. However, the 'ground level' datum used was different to that measured during the GPS survey. Therefore, groundwater elevations above AHD should be calculated by:*

1. *subtracting the 'height of top of casing above ground level' used for groundwater level measurements (Table 2-1) from the 'elevation of top of casing above AHD' (Table 2-1); then*
2. *subtracting the 'groundwater level depth below ground level'.*

Subtracting the 'groundwater level depth below ground level' from the surveyed ground level elevation would give erroneous results.)

The elevations of groundwater levels fell markedly from north-east to south-west. However, groundwater at 00BN03 appeared to form a mound between 00BN07 and 00BN04.

2.2.3 Groundwater EC values

EC values are listed in Table 2-1 and variation in EC values across the townsite on 21 September 2000 is mapped in Figure 2-1. Values changed little between the five measurement dates. The groundwater at 00BN07 was three to four times fresher than any other site. However, the EC values recorded for 00BN08 and 00BN09 were low considering that they were the furthest downslope. EC values at 00BN05 and 00BN06 were relatively high, but the highest EC values were from the shallowest piezometer at 00BN03. The piezometer at this site was located within colluvium, whereas most others were in the weathering rock zone, just above fresh bedrock.

2.3 Interpretation and discussion

This section presents an interpretation of the recharge, groundwater flow and discharge processes affecting Bencubbin, based on limited available information. It then discusses the risk of salinity and Section 2.4 lists options for managing the risk.

2.3.1 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 Bencubbin. There is also a brief discussion of recharge rates.

Table 2-1. Piezometer site, drilling, construction and groundwater details (groundwater levels for three dates and EC values for 12 September 2000)

Drill hole name	Easting[#]	Northing[#]	Depth drilled	Elevation of top of casing above AHD[##]	Height of top of casing above gl[###,$]	Elevation of top of screen above AHD[##]	Elevation of base of screen above AHD[##]	Groundwater level depth below gl[###]			EC
	(m)	(m)	(m)	(m)	(m)	(m)	(m)	21/7/00 (m)	21/9/00 (m)	12/12/00 (m)	(mS/m)
00BN01D	582506.2	6590766.4	7	354.9	0.50	350	348	dry	dry	dry	dry
00BN02D	582179.0	6591066.6	4	353.6	0.50	352	350	dry	dry	2.37	dry
00BN03D	582169.2	6590893.6	26	350.9	0.48	327	325	7.60	7.56	7.66	2720
00BN03I	582168.6	6590893.1	10	350.8	0.49	343	341	7.60	7.58	7.67	3990
00BN04D	582311.2	6590711.2	15	350.8	0.47	338	336	15.27	dry	14.20	dry
00BN05D	582150.4	6590520.8	25	345.4	0.52	322	320	17.61	17.57	17.52	3220
00BN06D	582075.6	6590731.1	21	346.9	0.56	328	326	17.56	17.47	17.43	3440
00BN07D	581810.9	6591235.5	27*	351.2	0.48	326	324	16.58	16.62	16.30	550
00BN07I	581811.6	6591237.0	15	351.2	0.50	338	336	dry	dry	dry	dry
00BN08D	581609.8	6590470.0	36	338.9	0.50	305	303	23.20	23.16	23.02	1780
00BN09D	582480.5	6589470.4	50	328.3	0.43	280	278	11.52	11.76	11.83	1610
00BN09I	582482.9	6589470.1	4	328.4	0.54	326	324	dry	dry	dry	dry

#: Australian Geodetic Datum 1984; ##: Australian Height Datum; ###: gl - ground level; *: bedrock struck at 24 m depth; $: heights used when groundwater levels were measured; they do not match the differences in elevation between the casing tops and ground levels recorded during the GPS survey of the piezometers

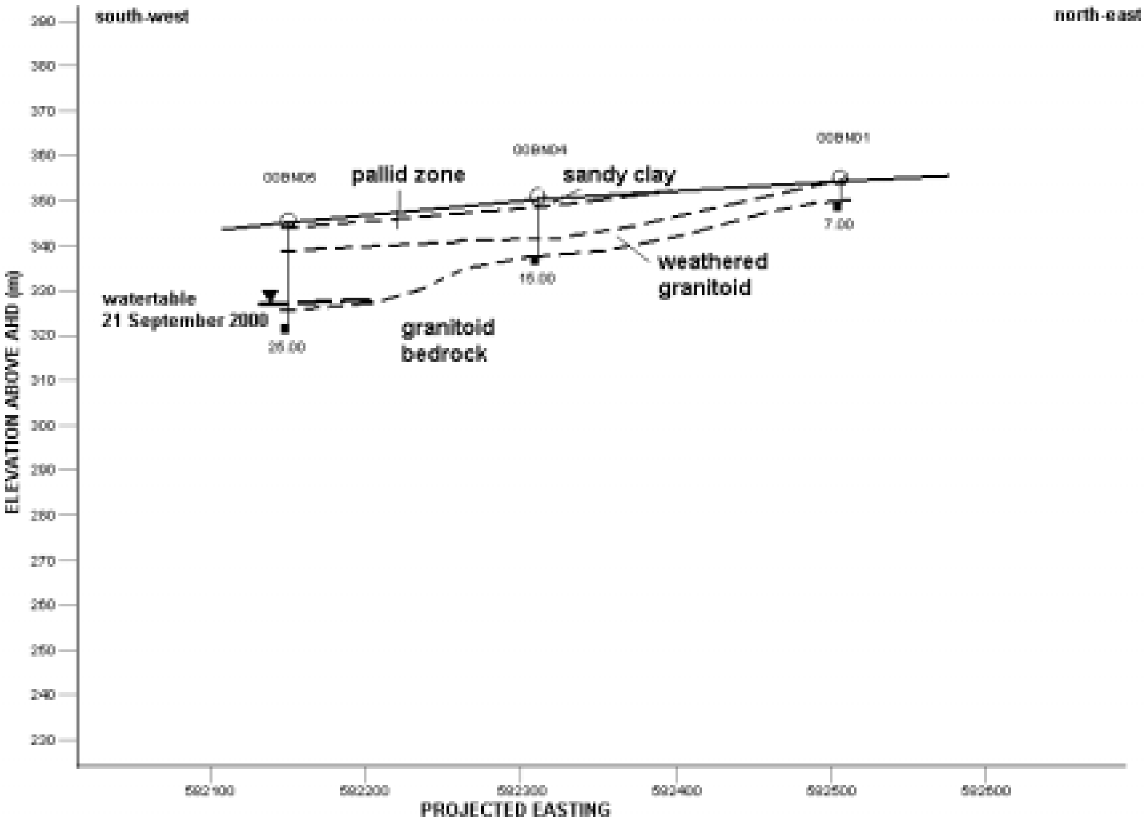

Figure 2-2. Cross-section from south-west to north-east (see Figure 2-1 for location)

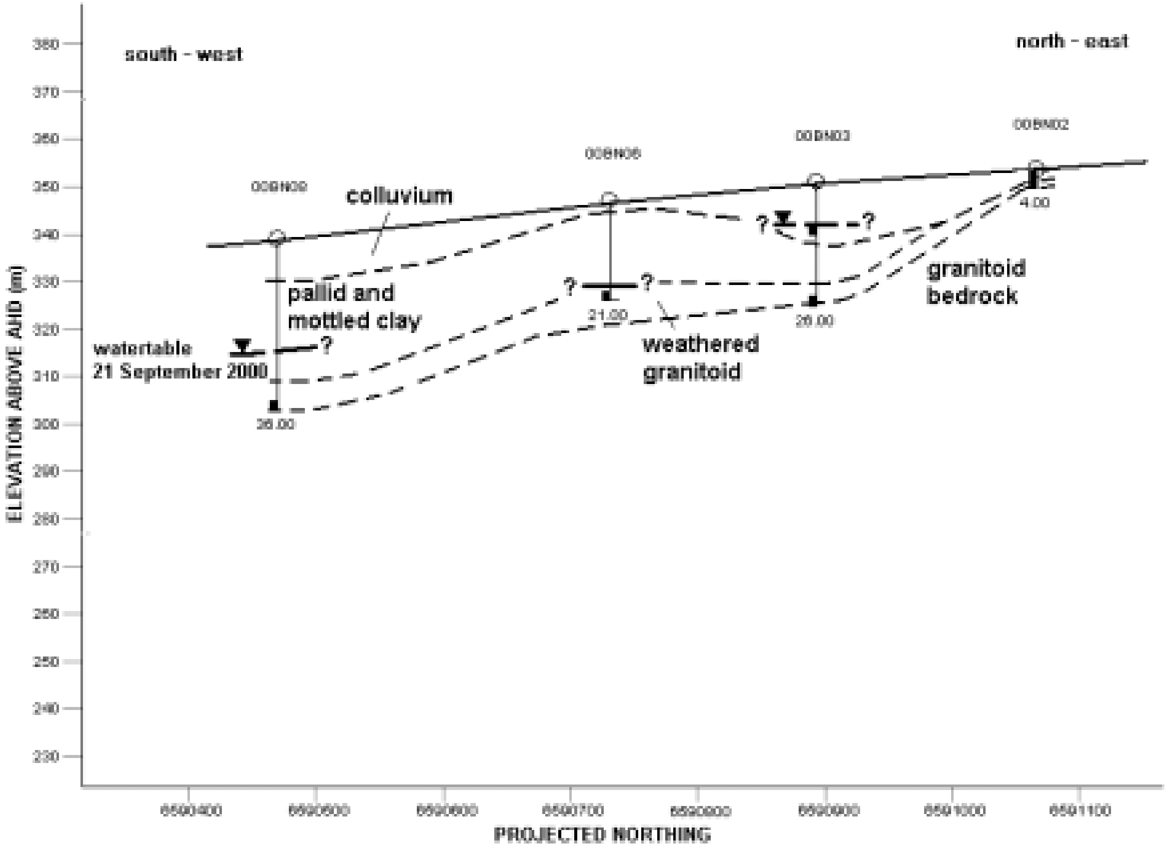

Figure 2-3. Cross-section from south-west to north-east (see Figure 2-1 for location)

2.3.1.1 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 land upslope from the townsite; and
3. the land 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 the ***upslope land zone*** can affect groundwater levels below the town if the groundwater systems below the zones are connected. In most cases, the source of recharge will be rain falling on the slopes and may be direct or indirect.

The groundwater system below the ***downslope zone*** can affect the groundwater levels below the townsite in two ways. Rising groundwater levels downslope may:

- cause the downslope 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 and around 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 slopes above or downslope, 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 other zones also make contributions.

2.3.1.2 Bencubbin recharge zones

No measurements of recharge have been made in or around the Bencubbin townsite. However, the landscape features and land uses can be used to make preliminary comparisons.

There is a relatively small area of slopes above the built-up area of the town, and most of this is under natural vegetation or used as a golf course. Aerial photographs show a distinct linear feature running west to east directly to the north of the built-up area. This was thought to be a mafic dyke. It is likely that such a prominent feature would act as a barrier to groundwater flow. Therefore, it was concluded that negligible groundwater flowed to the townsite zone from the slopes above.

Groundwater levels at sites downslope from the built-up part of the town (00BN08 and 00BN09) are at lower elevations than those within the town and are, therefore, unlikely to significantly affect the groundwater levels below the town.

The implication is that an important proportion of the recharge affecting groundwater levels below the Bencubbin townsite is likely to be occurring within the townsite zone. The source of the recharge could be rain falling on the townsite, run-off from the slopes surrounding the townsite (discussed in Section 3) and water imported into the townsite.

The early monitoring data indicate that groundwater levels below some parts of the town rose late in 2000. The cause is not known. It is unlikely that it was a delayed reaction to winter rain as reactions are likely to be rapid in this type of landscape. Rainfall records for the town show that only 5 mm of rain fell during the months of October, November and December 2000, so spring rainfall is also discounted as the cause. Other possibilities include overwatering with the onset of warmer weather and leakage from water supply pipes, septic systems or pools.

Long-term frequent and regular monitoring of groundwater levels can show where the important recharge areas are and when they are active. This will help to establish whether rain is a more important factor than imported water supplies within the townsite over the long-term. Therefore, the network is a valuable asset.

2.3.2 Groundwater flow systems

As noted in Section 1.2, there may be mafic dykes below the townsite which could act as barriers to groundwater flow. Blight *et al*. (1984) also mapped quartz dykes near the town. These could act as groundwater barriers or carriers.

Aerial photographs and drilling indicated that depth to bedrock was variable and that it was shallowest in places below the townsite (at site 00BN02 in particular). Groundwater depths and elevations also changed markedly across the townsite. These observations imply that groundwater systems may be compartmentalised and that there may be only poor hydraulic continuity, or none, between the groundwater systems below different parts of the townsite. It is not clear whether groundwater below the town is able to flow away towards the valley floor or whether it is impeded by geological barriers.

2.3.3 Assessment of salinity risk

At the sites drilled, the groundwater levels below Bencubbin were deep enough not to be causing problems, except at site 00BN02. It is likely that shallow bedrock occurs below other parts of the townsite which were not drilled. The records between July and December 2000 indicated that the shallow watertable was not a permanent feature there. However, it is possible that areas of shallow bedrock elsewhere below the town contain 'troughs', and these could trap permanent 'pools' of groundwater. There was not enough information to determine whether this is a significant problem.

There are no long-term groundwater records for the townsite, and so it is not known whether the groundwater levels are stable or are rising. Regular and frequent monitoring of the piezometer network over the long-term will indicate if there is a risk of salinity in the future.

2.4 Management options

Options for managing problems caused by shallow groundwater involve recharge reduction and groundwater abstraction. Some methods of reducing recharge have other benefits (e.g. reduced water supply costs, less waste of rainfall, less infrastructure damage from surface water) and should be considered. The watertables are too deep below the town for groundwater abstraction to be considered necessary.

It can be assumed that most groundwater rises below the townsite are sourced from water infiltrating within the town, and not from surrounding agricultural areas. Recharge below the town has not been measured or calculated, but it is possible that it is greater below features such as irrigated sports fields and gardens, dams, areas where run-off accumulates and ponds, bare soil including sand and gravel pits, and septic systems or sewage ponds. Ways to reduce recharge include:

- checking for and mending leaks from water pipes, pools, dams, drains and culverts;
- monitoring the amount of water required by gardens, parks and sports grounds and avoiding overwatering;
- replacing septic systems with a sewer system;
- preventing surface water from ponding in areas where it may become recharge;
- growing perennials on any bare land (including disused sand and gravel pits) and grassed areas.

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

3. Groundwater flow modelling

Authors: Cahit Yesertener and Shawan Dogramaci (Water and Rivers Commission)

Section 2.4 discussed a combination of approaches which could be effective in reducing the risk of shallow groundwater and salinity in Bencubbin. This section describes a computer groundwater flow model which was constructed to assess the impact of rising groundwater levels on the town.

Note that the modelling was based on limited data and a large number of assumptions and the results should be viewed with great caution (see warnings in Section 3.4).

First, a suitable conceptual model was constructed based on the results of the drilling investigation (Section 2) and topographic and climatic data. This conceptualisation was adapted to the three-dimensional groundwater flow simulation program Visual MODFLOW 2.8 (Waterloo Hydrogeologic 2000). The model was then used to simulate the effects of 'doing nothing differently' to determine the impacts of inaction.

Sections 3.1 and 3.2 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 3.3. Please note the warnings in Section 3.4 when considering the results.

3.1 Model construction and conceptualisation

Conceptually, the groundwater model consisted of three layers: the unconfined colluvium, leaky pallid zone, and leaky or semi-confined saprolite of the weathered granite as defined by the hydrogeological investigation (Section 2).

Inflow and outflow boundaries of the model domain are illustrated in Figure 3-1. The model domain covered an area of 2.38 km^2 and incorporated the majority of the bores in the townsite. Each cell in the domain was 20 m by 20 m, resulting in 85 columns and 70 rows, giving 5,950 cells.

The top of the unconfined layer was taken as the land surface, which was extracted from 2 m-contour digital elevation models (DEMs) for the catchment (map sheet 2436-2 NW, Spatial Resources Information Group, Agriculture Western Australia).

This information, together with depths to the base of the pallid zone and bedrock, was interpolated using kriging and then assigned to each model node. The inflow boundary in the east of the town was simulated as a constant head boundary, while the outflow boundary to the west was simulated through a general head boundary.

Two annual recharge rates, 15 and 25 mm, were applied to the model, based on topography and soil properties that were delineated from the hydrogeological investigation. The weighted average recharge rate of the two zones was approximately 6 per cent of the annual rainfall.

The initial hydraulic conductivities for all three layers were estimated using the soil and lithological descriptions from the drilling program (Section 2). Based on the lithological descriptions, the hydraulic conductivity values used for the three modelled layers varied spatially depending on topography and the landform characteristics (Figure 3-2).

3.2 Steady-state model calibration

Calibration of the steady-state model was accepted with a correlation coefficient of 0.996. The standard error and mean error were 0.39 m and 0.21 m respectively.

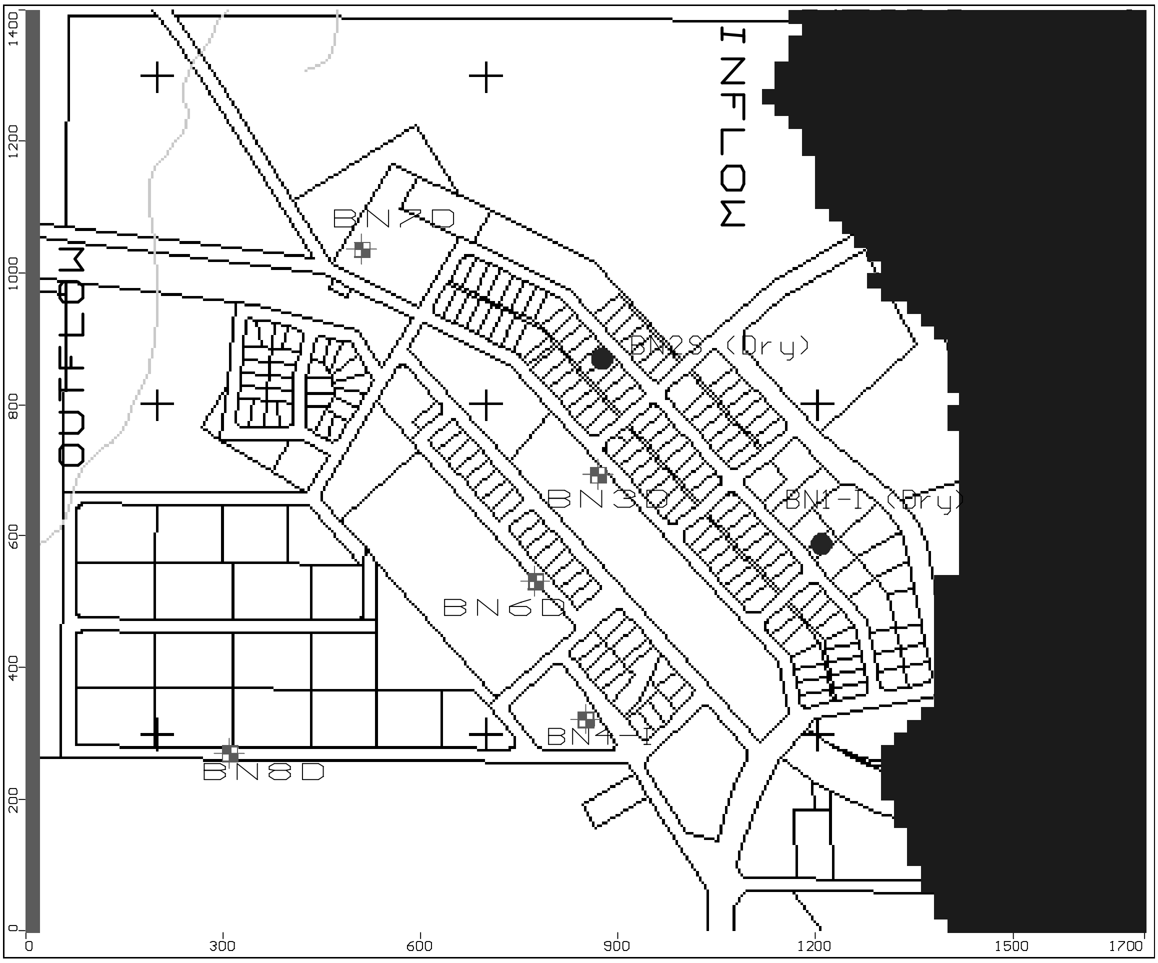

Figure 3-1. The boundary conditions (broad dark broken line to east of town is inflow boundary; broad lighter line along west edge of diagram is outflow boundary; scales along axes are in metres, top of map is north)

The recharge rate required to achieve the best calibration was approximately 6 per cent of annual rainfall, or 20 mm/year.

Simulated depths to the watertable for the calibrated model are shown in Figure 3-3. The model implied that the groundwater levels were between 3 and 20 m deep. Modelled groundwater travel paths are shown in Figure 3-4 and indicated that the travel time from the north-east to south-west beneath the townsite was about 20 years.

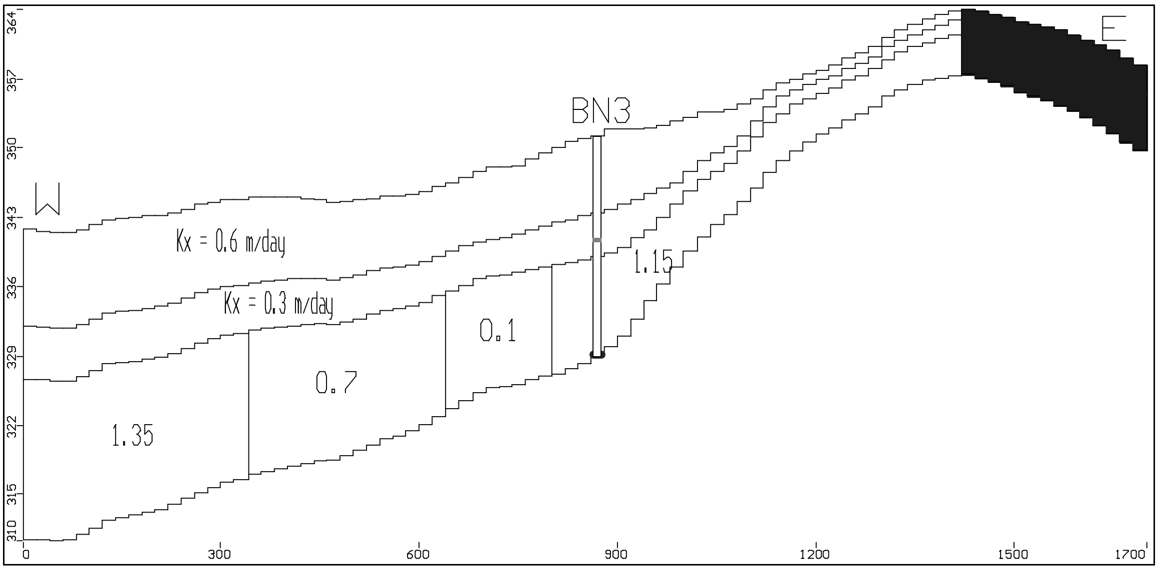

Figure 3-2. Hydraulic conductivity zones used in model calibration (in metres per day; axis scales are in metres) along a west-east cross-section through site 00BN03 (labelled BN3)

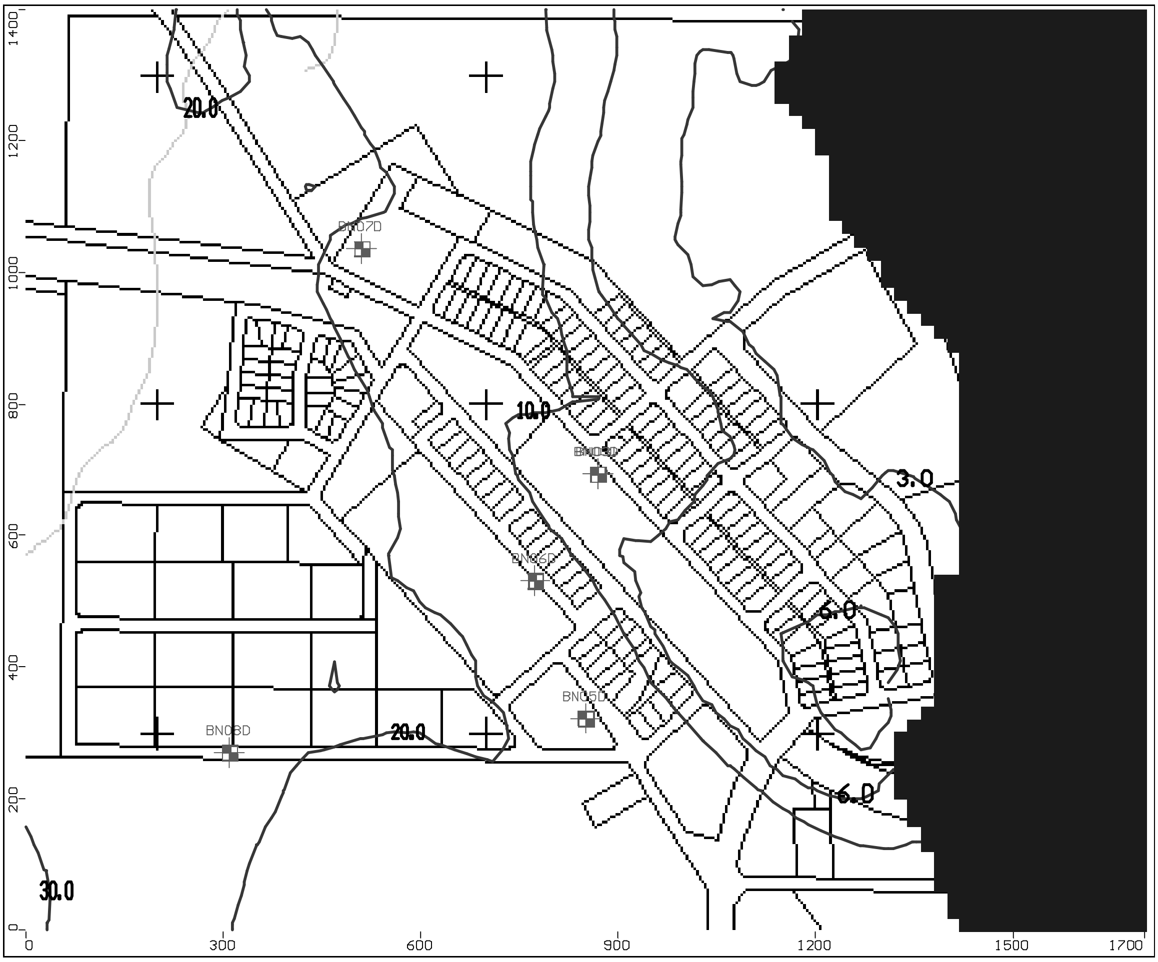

Figure 3-3. Depth to watertable (in metres) for the calibrated model (boundary scales in metres, top of map is north)

Figure 3-4. Shallow groundwater levels in metres above AHD and travel paths for the calibrated model (boundary scales in metres, top of map is north)

3.3 Dynamic simulations of strategies

The dynamic simulations extended over 30-year periods. The constant head boundary in the east and the general head boundary to the west of the domain area for the transient model were simulated to reflect a watertable rise at a rate 0.01 and 0.10 m/year respectively. This rate was based on watertable trend analysis that showed a general rise of groundwater ranging between 0.10 and 0.15 m/year in the Bencubbin and surrounding catchments (Nulsen 1998).

3.3.1 '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 20 mm/year over 30 years.

Under current management practices, it was predicted that the watertable below the town would not come within 3 m of ground level within the next 30 years (Figure 3-5).

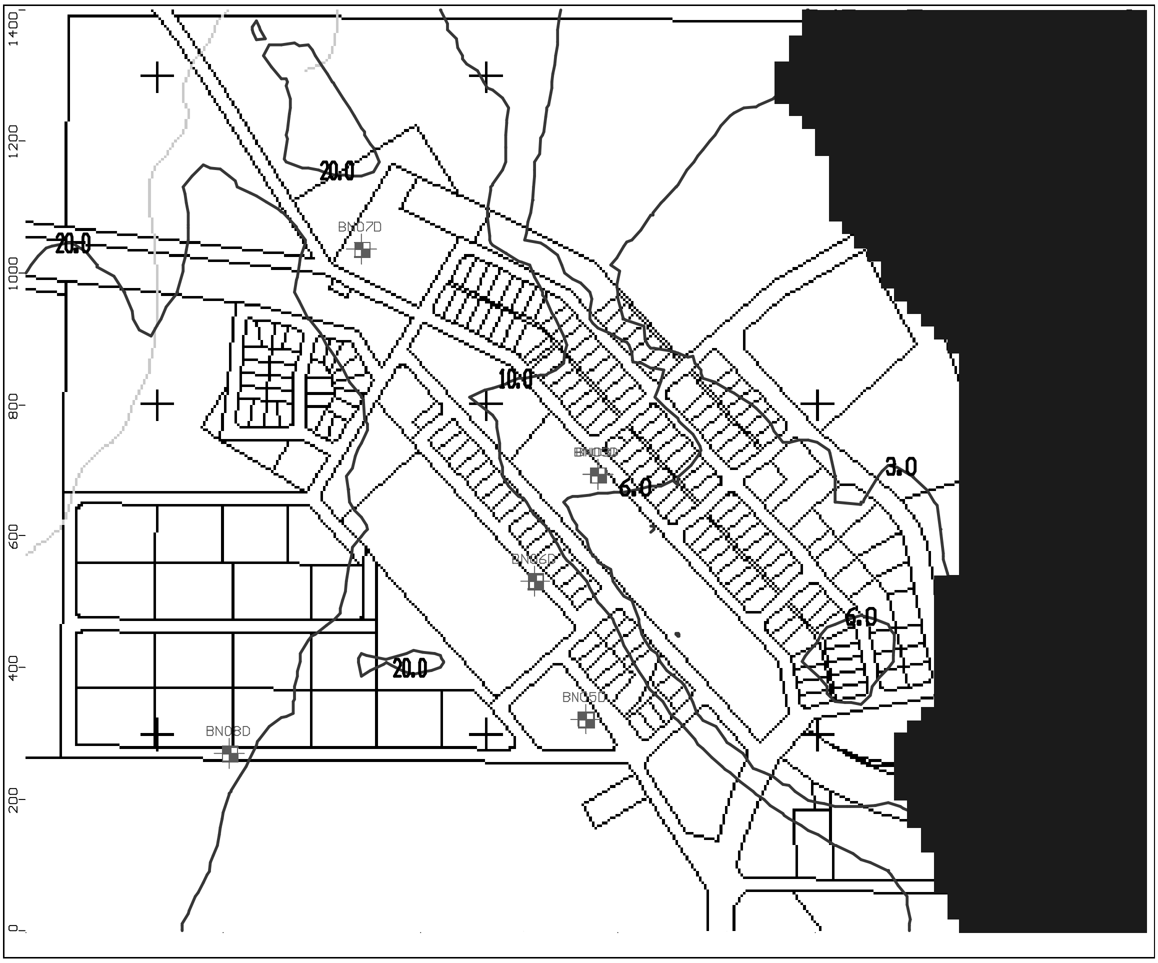

Figure 3-5. Depth to watertable (in metres) after 30 years under the 'do nothing differently' strategy (boundary scales in metres, top of map is north)

3.4 Warning - discussion of model

The groundwater modelling in Bencubbin was undertaken using limited data and information:

- The model design did not simulate any groundwater barriers or groundwater carriers, although it is likely these occur (Section 2).
- Models should be calibrated for several dates to cover the range of groundwater levels which occur. Because of limited groundwater level data, the model was only calibrated in steady-state against heads measured on one date. The assumption of a steady-state groundwater system is inappropriate, but represents the best method for applying a groundwater model to the town.
- Models should also be validated using independent data sets. Since no independent data were available, the model was not validated.
- The model results are sensitive to both the recharge rate and values of hydraulic conductivity used, but the values used were only estimated from limited information or assumed, not measured.
- The model results are very dependent on the DEM data (which represents the land surface elevation) and on the locations of the inflow and outflow

boundaries. It is possible that there are inaccuracies in the DEM data set and the locations of groundwater inflow and outflow were only assumed, not measured.

- Rates of groundwater rise along parts of the model boundaries were assumed, although it is not known whether they are stable or rising over the long-term, nor how the rates vary along the boundaries. If the rate of watertable rise is quicker or slower than the rate assumed, then the effects will be correspondingly sooner or later.
- Recharge was applied evenly across all of the modelled area, but in reality, it will vary spatially.

Therefore, the results from the modelling are indicative only and may not represent what is happening in the town.

4. Flood risk analysis

Authors: Shahram Sharafi and Ali Mahtab (Agriculture Western Australia)

4.1 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 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 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.

4.2 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.

4.2.1 Available information

The following information was collated for the Bencubbin town 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). Note that calculations were made for the catchment of the watercourse (at a point downstream of the townsite) which runs to the west of the townsite, rather than for the catchment of the townsite.

4.2.2 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 30 per cent of the town area of 86 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.

A system of pipes and open drains carry run-off through the town. The natural drainage lines are predominantly north-south through the town and discharge into the drainage line to the south-west. The grain depot is located in the south-east of the town and a new (southern) bin has guttering discharging onto bitumen. There are a few rock exposures near the depot and storm water is drained into a drainage line about 1 m deep and 2 m wide via a 20 cm-diameter drainage pipe. There is a roaded catchment next to a Water Corporation dam to direct storm water to the dam. Four major drainage pipes (20 cm-diameter) and a culvert (60 cm wide by 30 cm high) allow water to drain from one side to the other on the railway line.

4.3 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 Bencubbin town catchment, parameters used for a calibrated model derived for the Moora townsite (Ali *et al*. 2001) were substituted.

4.4 Results

Results are summarised in Tables 4-1 and 4-2.

Table 4-1. Peak flood flow for 2-, 5-, 10-, 20-, 50- and 100-year ARI storms for the catchment of the town of Bencubbin

ARI (years)	Peak flood (m^3/s)
2	0.5
5	1.2
10	2.1
20	4.3
50	7.9
100	14.6

Table 4-2. Run-off volumes for 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	27.62	27.62	55,490	23,780
	6	8.43	50.58	101,620	43,550
	24	3.21	77.04	154,770	66,330
50	1	34.78	34.78	69,870	29,950
	6	10.38	62.28	125,120	53,620
	24	4.14	99.36	199,610	85,550
100	1	40.91	40.91	82,190	35,220
	6	12.92	77.52	155,740	66,740
	24	4.96	119.04	239,150	102,490

4.5 Flood risk assessment

The criteria to classify a town's relative flood risk level were based on the calculated rates of flow and 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 4-3 shows the flood risk to the town of Bencubbin for 20-, 50- and 100-year ARI storm events of 24 hours duration.

Table 4-3. Flood risk to Bencubbin 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	4.3	221,100	Low	Low	Low
50	7.9	285,200	Low	Low	
100	14.6	341,600	Medium	Low	

4.6 Conclusion

The flow accumulation modelling and the UDD model results revealed that Bencubbin is at low risk from flooding. However, localised flooding may occur in low-lying areas of the townsite.

4.7 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).

5. Conclusions and recommendations

Bencubbin townsite is not currently affected by salinity, although shallow groundwater may be causing seepage in the cellar of the hotel. Frequent, regular long-term groundwater level measurements are required to assess whether the watertable is rising and to determine if other parts of the town are at risk. Such groundwater records would also show which areas are the most important recharge zones and could indicate whether groundwater bodies below different parts of the town are well-connected.

There are opportunities to reduce the recharge occurring within and around the townsite, and doing so may have additional benefits. It would, therefore, be wise to adopt some recharge reduction measures immediately while waiting for enough data to make a risk assessment.

5.1 Recommendations

1. Adopt those methods of reducing townsite recharge which will also provide other benefits (see suggestions in Section 2.4).

2. Measure groundwater levels in the monitoring network monthly and analyse and review them annually. Continue with this monitoring for at least 10 years to determine whether groundwater levels are rising, and where and when most recharge occurs.

6. Acknowledgments

Jim Prince and Ed Solin (Agriculture Western Australia, South Perth) helped collect the information for the hydrogeological investigation.

7. References

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Borehole 00BN01D

RURAL TOWNS PROJECT

582506.17 UTM E 6590766.4 UTM N 355.416 UTM RL UTM Grid: AGD 84

Hydrologist/Supervisor: P LACEY

Town: BENCUBBIN

Notes/Location: Brown Street

Date Drilled: 04/07/2000

Hole Depth (m): 7

Drill Method: RC

Hole Diameter: 125

Driller: L A Boyle

Agriculture WESTERN AUSTRALIA

From m	To m		Geology	Moisture	Water Level
0	1	H H H	**Weathered granite** Gray clayey sand, weathered granite profile, some granite chips, dry.		
1	2	H H H	**Weathered granite** Pink clayey sand, weathered granite profile, dry.		
2	3	H H H	**Weathered granite** White clayey sand, weathered granite profile, dry.		
3	4	H H H	**Weathered granite** Pink and white clayey sand, weathered granite profile, dry.		
4	5	H H H	**Weathered granite** Gray weathered granite, dry.		
5	7	+ + + +	**Granite** Gray weathered to fresh granite, chips, dry.		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00BN01D	50MM PVC	7		2	Gravel, Bentonite seal			

Borehole 00BN02D

RURAL TOWNS PROJECT

582179	UTM E	6591066.6	UTM N	354.123	UTM RL	UTM Grid:	AGD 84

Hydrologist/Supervisor:	P LACEY	Date Drilled:	04/07/2000
Town:	BENCUBBIN	Hole Depth (m):	4
Notes/Location:	Behind hotel	Drill Method:	RC
		Hole Diameter:	125
		Driller:	L A Boyle

Agriculture
WESTERN AUSTRALIA

From m	*To m*		*Geology*	*Moisture*	*Water Level*
0	1	OOOOOO OOOOOO OOOOOO OOOOOO OOOOOO OOOOOO	**Sandy clay** Yelow sandy clay, dry.		
1	2	H H H H H H H H H H H H H H H H H H	**Weathered granite** Yellow and white consolidated sand/rock weathered granite, dry.		
2	3	H H H H H H H H H H H H H H H H H H	**Weathered granite** Gray weathered granite, dry.		
3	4	+ +	**Granite bedrock** Gray granite bedrock, chips, dry.		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00BN02D	50MM PVC	4		2	Gravel, Bentonite seal			

Borehole 00BN03D

RURAL TOWNS PROJECT

582169.15 UTM E 6590893.6 UTM N 351.769 UTM RL UTM Grid: AGD 84

Hydrologist/Supervisor: P LACEY

Date Drilled: 04/07/2000

Town: BENCUBBIN

Hole Depth (m): 26

Notes/Location: AGWA office carpark

Drill Method: RC

Hole Diameter: 125

Driller: L A Boyle

From m	To m	Geology	Moisture	Water Level
0	1	**Colluvial sediments** Gray clayey sand, colluvial sediments, dry.		
1	2	**Sandy clay** Brown and gray fine sandy clay, dry.		
2	3	**Sandy clay** Gray fine sandy clay, dry.		
3	4	**Sandy clay** Pink fine sandy clay, dry.		
4	5	**Sandy clay** Pink and white fine sandy clay, moist.	Moist	
5	7	**Sandy clay** White fine sandy clay, moist	Moist	
7	13	**Sandy clay** Gray sandy clay, moist	Moist	
13	14	**Pallid zone** White kaolin clay, pallid zone, moist	Moist	
14	15	**Clay** Gray and white kaolin clay, quartz grains and feldspar under 5mm, wet.	Wet	
15	16	**Sandy clay** Gray and brown sandy clay, wet.	Wet	
16	21	**Clay** Yellowy brown clay, wet.	Wet	
21	22	**Weathered granite** Gray weathered granite some chips, wet.	Wet	
22	23	**Weathered granite** yellowy brown sandy clay and weathered granite, wet.	Wet	
23	25	**Weathered granite** Gray weathered granite, 10mm chips, wet.	Wet	

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00BN03D	50MM PVC	26		2	Gravel, Bentonite seal			
00BN03I	50MM PVC	10		2	Gravel, Bentonite seal			

Borehole 00BN03D

RURAL TOWNS PROJECT

582169.15	UTM E	6590893.6	UTM N	351.769	UTM RL	UTM Grid:	AGD 84

Hydrologist/Supervisor:	P LACEY	Date Drilled:	04/07/2000
Town:	BENCUBBIN	Hole Depth (m):	26
Notes/Location:	AGWA office carpark	Drill Method:	RC
		Hole Diameter:	125
		Driller:	L A Boyle

25	26	+ +	**Granitic bedrock** Quartz rich granitic bedrock.	

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00BN03D	50MM PVC	26		2	Gravel, Bentonite seal			
00BN03I	50MM PVC	10		2	Gravel, Bentonite seal			

Borehole 00BN04D

RURAL TOWNS PROJECT

582311.24 UTM E 6590711.2 UTM N 351.265 UTM RL UTM Grid: AGD 84

Hydrologist/Supervisor: P LACEY

Date Drilled: 04/07/2000

Town: BENCUBBIN

Hole Depth (m): 15

Notes/Location: Community bore. Next to information bay

Drill Method: RC

Hole Diameter: 125

Driller: L A Boyle

From m	*To m*		*Geology*	*Moisture*	*Water Level*
0	1	░	**Sandy clay** Gray sandy clay, dry.		
1	2	░	**Sand** Yellow sand, dry.		
2	6	░	**Pallid zone** White pallid kaolin clay with weathered granite chips, dry.		
6	9	░	**Pallid zone** White pallid kaolin clay, dry.		
9	13	H H H	**Weathered granite** Gray weathered granite, dry.		
13	15	+ + + +	**Granitic bedrock** Gray weathered granite to granitic bedrock, 20mm chips containing quartz, feldspar and mica, dry.		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00BN04D	50MM PVC	15		2	Gravel, Bentonite seal			

Borehole 00BN05D

RURAL TOWNS PROJECT

Agriculture
WESTERN AUSTRALIA

582150.37 UTM E 6590520.8 UTM N 345.954 UTM RL UTM Grid: AGD 84

Hydrologist/Supervisor: P LACEY
Town: BENCUBBIN
Notes/Location: At the new caravan site
Date Drilled: 04/07/2000
Hole Depth (m): 25
Drill Method: RC
Hole Diameter: 125
Driller: L A Boyle

From m	To m		Geology	Moisture	Water Level
0	1	⁘	**Sandy clay** Brown sandy clay, dry.		
1	3	⁘	**Weathered granite** Pink sandy clay, weathered granite profile, dry.		
3	6	⁘	**Weathered granite** White sandy clay, weathered granite profile, dry.		
6	14	H H H	**Weathered granite** Gray powery clay,weathered granite profile, dry.		
14	15	H H H	**Weathered granite** Dark brown powery clay, weathered granite profile, dry		
15	20	H H H	**Weathered granite** Gray powery clay, weathered granite profile, dry.		
20	23	+ + + +	**Granitic bedrock** Gray weathered granite to granitic bedrock, dry.		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00BN05D	50MM PVC	25		2	Gravel, Bentonite seal			

Borehole 00BN06D

RURAL TOWNS PROJECT

582075.62 UTM E 6590731.1 UTM N 347.479 UTM RL UTM Grid: AGD 84

Hydrologist/Supervisor: P LACEY

Town: BENCUBBIN

Notes/Location: Next to the oval

Date Drilled: 04/07/2000

Hole Depth (m): 21

Drill Method: RC

Hole Diameter: 125

Driller: L A Boyle

From m	To m	Geology	Moisture	Water Level
0	2	**Sandy clay** Gray sandy clay, dry		
2	4	**Pallid zone** Pink kaolin clay, pallid zone, dry.		
4	6	**Pallid zone** White kaolin clay, pallid zone, dry.		
6	9	**Pallid zone** Pink kaolin clay, pallid zone, dry.		
9	10	**Pallid zone** White gritty kaolin clay, pallid zone, dry.		
10	12	**Sandy clay** Yellow sandy clay, dry.		
12	13	**Sandy clay** Gray sandy clay, dry		
13	15	**Sandy clay** Yellow and gray sandy clay, dry.		
15	17	**Sandy clay** Yellowy brown sandy clay, dry.		
17	18	**Sandy clay** Yellow sandy clay, dry.		
18	19	**Weathered granite** Gray weathered granite gritty, dry.		
19	21	**Weathered granite** Gray weathered granite, chips, dry.		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00BN06D	50MM PVC	21		2	Gravel, Bentonite seal			

Borehole	**00BN07D**			**RURAL TOWNS PROJECT**			
581810.89	UTM E	6591235.5	UTM N	352.176	UTM RL	UTM Grid:	AGD 84

Hydrologist/Supervisor:	P LACEY	Date Drilled:	05/07/2000
Town:	BENCUBBIN	Hole Depth (m):	27
Notes/Location:	School	Drill Method:	RC
		Hole Diameter:	125
		Driller:	L A Boyle

From m	***To m***	***Geology***	***Moisture***	***Water Level***
0	1	**Gravely sand** Pink gravley sand, weathered granite profile, dry.		
1	6	**Gravely sand** Pink fine gravley sand, weathered granite profile, dry.		
6	9	**Gravely Clay** White gravley clay, weathered granite profile, dry.		
9	12	**Sandy clay** White fine sandy clay, weathered granite profile, dry.		
12	13	**Sandy clay** White and yellow fine sandy clay, weathered granite profile, moist.	Moist	
13	14	**Sandy clay** White fine sandy clay, weathered granite profile, moist.	Moist	
14	15	**Sandy clay** White and gray fine sandy clay, weathered granite profile, moist.	Moist	
15	16	**Sandy clay** Gray and yellow fine sandy clay, weathered granite profile, moist.	Moist	
16	17	**Sandy clay** Brown fine sandy clay, weathered granite profile, moist.	Moist	
17	19	**Clay** Light brown clay, moist.	Moist	
19	21	**Clay** Light brown clay, wet.	Wet	
21	22	**Sandy clay** Brown fine sandy clay, moist.	Moist	
22	24	**Sandy clay** Light brown fine sandy clay, moist.	Moist	
24	27	**Granitic bedrock** Granitic bedrock, dry.		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00BN07D	50MM PVC	27		2	Gravel, Bentonite seal			
00BN07I	50MM PVC	15		2	Gravel, Bentonite seal			

Borehole 00BN08D

RURAL TOWNS PROJECT

581609.84 UTM E 6590470.0 UTM N 339.39 UTM RL UTM Grid: AGD 84

Hydrologist/Supervisor: P LACEY
Town: BENCUBBIN
Notes/Location: Below dam south of town.

Date Drilled: 05/07/2000
Hole Depth (m): 36
Drill Method: RC
Hole Diameter: 125
Driller: L A Boyle

From m	To m	Geology	Moisture	Water Level
0	1	**Sand** Light brown sand, dry.		
1	2	**Gravelly sand** Dark orange gravley sand, moist.	Moist	
2	3	**Gravelly sand** Light brown gravley sand, dry.		
3	4	**Sandstone** Light orange gravley sand, 10mm chips siliceous sandstone, dry.		
4	5	**Sandstone** Orangey pink gravley sand, siliceous sandstone, dry.		
5	6	**Sandstone** Light yellow gravley sand, 10mm chips siliceous sandstone, dry.		
6	8	**Sandstone** Pink gravley sand, 10mm chips siliceous sandstone, dry.		
8	9	**Sandstone** Pink gravley sand, siliceous sandstone, dry.		
9	11	**Pallid zone** White and pink gravley sand, 5mm chips, siliceous and cemented pallid zone clay, dry.		
11	19	**Clay** Purple kaolin clay, dry		
19	22	**Clay** Purple kaolin clay, moist.	Moist	
22	23	**Clay** Purple kaolin clay, wet.	Wet	
23	24	**Sandy clay** Yellow and white mottled sandy clay, wet.	Wet	
24	25	**Clay** Purple kaolin clay, wet.	Wet	

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00BN08D	50MM PVC	36		2	Gravel, Bentonite seal			

Borehole 00BN08D

RURAL TOWNS PROJECT

581609.84	UTM E	6590470.0	UTM N	339.39	UTM RL	UTM Grid:	AGD 84

Hydrologist/Supervisor:	P LACEY	Date Drilled:	05/07/2000
Town:	BENCUBBIN	Hole Depth (m):	36
Notes/Location:	Below dam south of town.	Drill Method:	RC
		Hole Diameter:	125
		Driller:	L A Boyle

25	30		**Clay** Light brown clay, wet.	Wet
30	33	H H H H H H H H H H H H H H H H H H	**Weathered granite** Dark brown, very weathered granite, fine sandy clay, moist	Moist
33	36	H H H H H H H H H H H H H H H H H H	**Weathered granite** Gray weathered granite, 5mm chips, dry.	

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00BN08D	50MM PVC	36		2	Gravel, Bentonite seal			

Borehole 00BN09D

RURAL TOWNS PROJECT

582480.52 UTM E 6589470.4 UTM N 329.321 UTM RL UTM Grid: AGD 84

Hydrologist/Supervisor: P LACEY
Date Drilled: 05/07/2000
Town: BENCUBBIN
Hole Depth (m): 50
Notes/Location: Next to the Go-cart track.
Drill Method: RC
Hole Diameter: 125
Driller: L A Boyle

From m	To m		*Geology*	*Moisture*	*Water Level*
0	1	○○○	**Gravely sand** Brown gravely sand, moist.	Moist	
1	4	⁘	**Sandstone** Brown gravely sand, siliceous sandstone, dry.		
4	5	⁘	**Pallid zone** Gray gravely sand, siliceous pallid clay, dry.		
5	6	⁘	**Pallid zone** White gravely clay, siliceous pallid clay, dry.		
6	11	⁘	**Pallid zone** White kaolin clay, pallid zone,moist.	Moist	
11	13	⁘	**Pallid zone** Pink kaolin clay, pallid zone,moist.	Moist	
13	14	⁘	**Pallid zone** Orange kaolin clay, pallid zone,moist.	Moist	
14	15	⁘	**Pallid zone** Orange and white mottled kaolin clay, pallid zone,moist.	Moist	
15	32	⁘	**Pallid zone** White and pink kaolin clay, pallid zone,moist.	Moist	
32	34	⁘	**Pallid zone** White kaolin clay, pallid zone, wet.	Wet	
34	36	⁘	**Sandy clay** Orange sandy clay, moist.	Moist	
36	38	⁘	**Sandy clay** Gray sandy clay, moist.	Moist	
38	39	⁘	**Sandy clay** Orange sandy clay, moist.	Moist	
39	40	⁘	**Sandy clay** Gray sandy clay, moist.	Moist	

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00BN09D	50MM PVC	50		2	Gravel, Bentonite seal			
00BN09I	50MM PVC	4		2	Gravel, Bentonite seal			

Borehole **00BN09D**

RURAL TOWNS PROJECT

582480.52 UTM E 6589470.4 UTM N 329.321 UTM RL UTM Grid: AGD 84

Hydrologist/Supervisor: P LACEY

Town: BENCUBBIN

Notes/Location: Next to the Go-cart track.

Date Drilled: 05/07/2000

Hole Depth (m): 50

Drill Method: RC

Hole Diameter: 125

Driller: L A Boyle

40	46	▒	**Sandy clay** Greeny gray fine sandy clay, moist.	Moist		
46	50	▒	**Clay** Gray, green and white clay, wet.	Wet		

Hole	Casing Type	Casing m	AGL m	Screen m	Material Screened	Est. Yield	SWL (m)	SWL 2 (m)
00BN09D	50MM PVC	50		2	Gravel, Bentonite seal			
00BN09I	50MM PVC	4		2	Gravel, Bentonite seal			