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Resource Management Technical Report 225

Rural Towns
Program

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 Woodanilling. It aimed to accelerate the implementation of effective salinity management options and consisted of a drilling investigation and installation of a piezometer network, groundwater flow modelling and a flood risk analysis.

Nineteen piezometers were installed at 11 sites. Granitoid bedrock was struck at depths between about 6 and 29 m. The deepest bedrock was found along a linear zone striking north-eastwards from the valley floor towards an area of exposed bedrock in the highest part of the town. Drilling found shallow bedrock west of the exposure, and this was thought to be part of a bedrock ridge extending west from the high ground to the valley floor. The regolith consisted of residuum overlain by colluvium and alluvium.

Groundwater level depths were shallowest (only about 1 m deep) at the sites closest to the Boyerine Creek, and deepest (about 13 m below ground level) at the site highest in the landscape, in the north-east of the town. Groundwater electrical conductivity values generally increased in a downslope direction, from about 1,500 to about 3,000 mS/m. However, the lowest values were found in a shallow piezometer in a lower slope location on the northern edge of the townsite.

It was concluded that the main sources of the groundwater below the townsite were recharge occurring within the townsite and groundwater inflow from groundwater systems below the valley floor of the Boyerine Creek, although some groundwater could also flow to the townsite from below the agricultural land to the east of the town. There are not yet enough groundwater level data to determine where and when most recharge occurs, or whether groundwater levels are stable or rising. Therefore, it is essential that the piezometer network is monitored frequently and regularly for a long-time.

There are opportunities to reduce the recharge occurring within the townsite, and some of these would have additional benefits. A large reduction in recharge below the agricultural land to the south, east and west of the townsite would also improve the problem, but it was assumed that this would be more difficult to achieve. Because of the bedrock and regolith geology, groundwater abstraction would have only limited impacts on the watertable levels.

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1. Introduction and background information

Author: Ben Whitfield (Agriculture Western Australia)

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

For Woodanilling, the groundwater study included a drilling program, installation of a groundwater monitoring network, groundwater flow modelling and a flood risk analysis. This report documents the background information for the town and its catchment (this section) and the hydrogeological and flood risk investigations (Sections 2 to 4) and then recommends steps for managing the salinity issues of the town effectively (Section 5).

The town of Woodanilling is 252 km south-east of Perth (Figure 1-1). Its population is about 110 and the Shire of Woodanilling has around 435 people. Woodanilling townsite comprises residential, light industrial and recreational land use. The town income is predominantly from servicing the surrounding agricultural area.

1.1 Description of the town catchment

Woodanilling is in the middle reaches of the fifth-order Boyerine Creek catchment of the Blackwood River basin (Figure 1-1). It is south-east of Lake Norring and the creek discharges into the lake. The headwaters of Boyerine Creek are a dense network of incised streams in farmland.

The gazetted townsite straddles the catchment's main drainage line (Figure 1-2), but most of the built-up area is on the floodplain and lower slopes, east of the creek.

1.2 Geology

The catchment area is underlain by granitoid rocks that contain small mafic and ultramafic remnants of dolerite and diorite (Chin and Brakel 1986). The granitoid is medium- and coarse-grained biotite granite and adamellite. Mostly, it is even-grained and shows local foliation, but small outcrops of porphyritic granite and adamellite with microcline phenocrysts occur approximately 2 km to the west of the town on the catchment divide.

Most of the town is on a unit of colluvium and minor alluvium (Chin and Brakel 1986). In the townsite, this unit is on slopes below rock and ironstone exposures and consists of silt, sand and gravel. There is also alluvium (silt and sand) below the broad valley floor that is to the south, west and north of the town. The deposits on the slopes overlie 'laterite' profiles of mottled and pallid, light- to medium-textured clays over coarse-grained, partly-weathered granite, over 'fresh' granitic bedrock. The thickness of the lateritic profile varies.

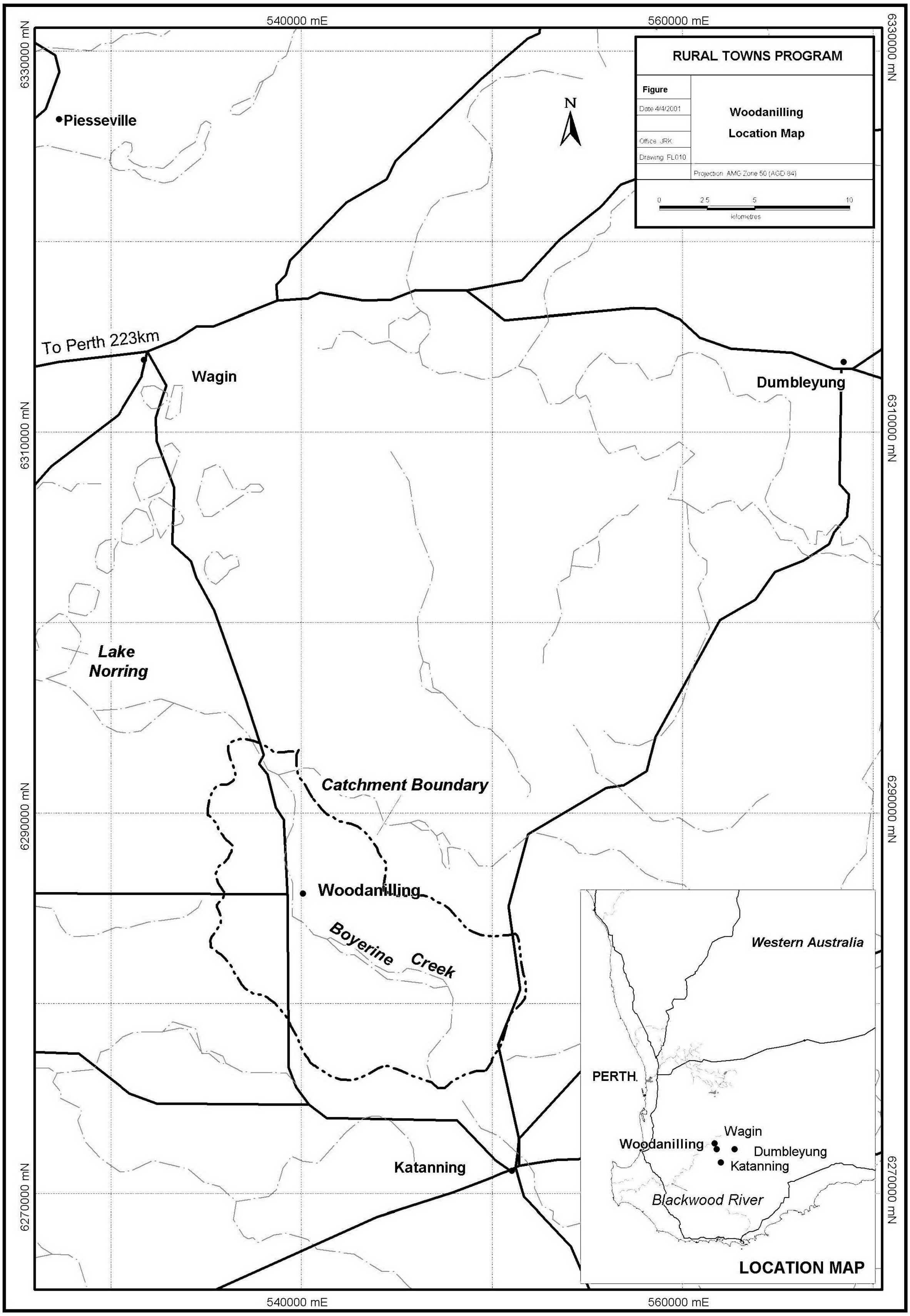

Figure 1-1. Regional setting of the Woodanilling townsite

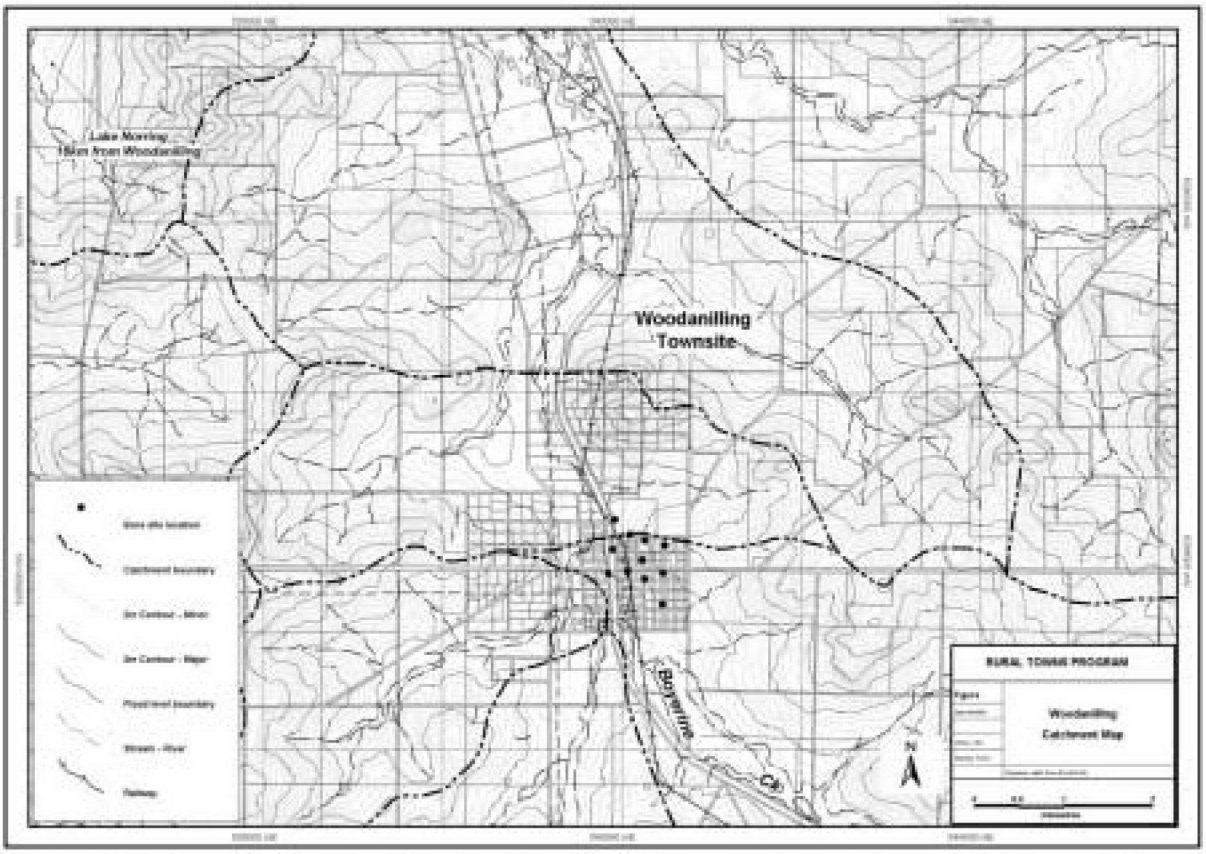

Figure 1-2. Location of the Woodanilling townsite within the middle reaches of the Boyerine Creek catchment

1.3 Climate

The climate is characterised by cool moist winters and warm to hot, dry summers. Most rainfall is received between May and August, however thunderstorms and out-of-season fronts can provide localised rainfall over summer. Estimated average annual class A pan evaporation for Katanning (Figure 1-1) is 1473 mm (Luke *et al*. 1987).

Long-term, average annual rainfall for Woodanilling in the period 1916 to 1999 was 464 mm (Bureau of Meteorology 2000, pers. comm.). The 10-year moving average indicates a below-average rainfall trend since the mid-1970s.

1.4 Hydrogeology

McCombe and Ye (1999) produced a hydrogeology map (scale of 1:250,000) that differentiated between aquifers in the alluvium and colluvium below the valley floor of the Boyerine Creek, and aquifers in weathered rock materials on the valley slopes. Their isohalines indicated that groundwater below the Woodanilling townsite would have between 3000 and 7000 mg/L total dissolved solids.

2. Hydrogeology investigation

Authors: Ben Whitfield (Agriculture Western Australia) and Fay Lewis (Fay Lewis Consulting)

The hydrogeology investigation aimed to determine which salinity management options would be most effective in Woodanilling. The investigation included a drilling program coupled with the installation of a groundwater monitoring network, and groundwater flow modelling. The methods used, the results and the interpretations of the results are described in Sections 2.2 to 2.4. Salinity management options are discussed in Section 2.5 and the effects of some of these were tested using a groundwater flow model (described in Section 3).

2.1 Pre-existing data

At the commencement of this project, the data available consisted of:

- 2-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);
- AQWABase (Water and Rivers Commission database) drilling and groundwater records;
- 1:25,000-scale colour aerial photographs (produced by the Department of Land Administration in 1996);
- two pre-existing bores (drilled to 8.5 and 2.5 m) at one site (Figure 2-1) were established by Agriculture Western Australia and the local landcare group in 1992 (no monitoring records were available from these).

2.2 Meathod

A drilling program was undertaken in the townsite from 9 to 12 June 2000, during which 19 piezometers were installed at 11 locations (Figure 2-1). No production bore was installed because the profiles were dominated by clays, and groundwater yields were expected to be low.

2.2.1 Drill site selection

Drill site selection was based on site accessibility and the need to have an indication of bedrock depth throughout the town. One bore at each drilling site, except 00BY03, was drilled to bedrock. All bedrock bores formed a pair with an intermediate or shallow piezometer.

A 'community awareness site' (00BY02) was placed in a prominent part of town.

Site 00BY08S was established in colluvial gravels to investigate the cause of waterlogging on the recreation oval.

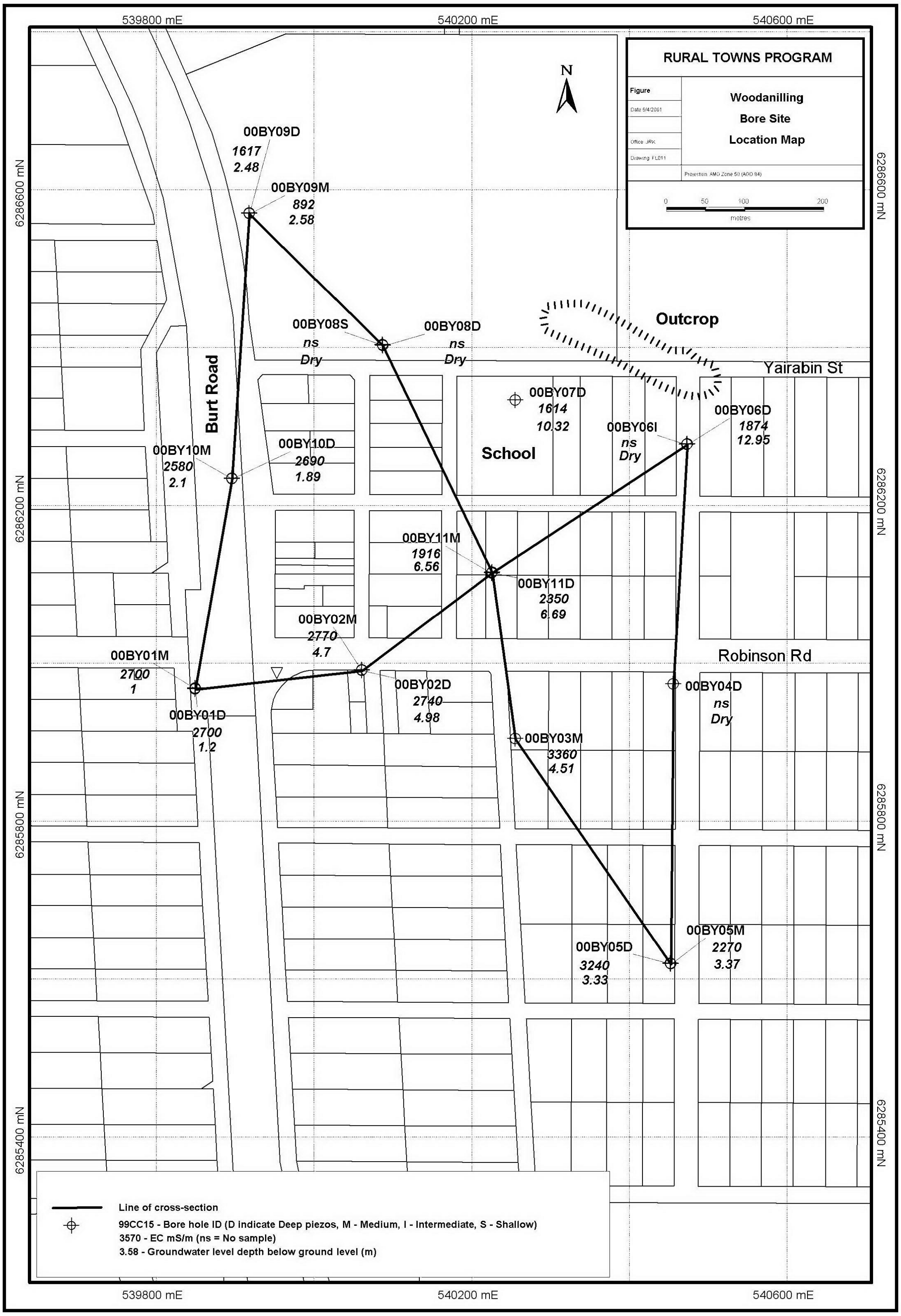

Figure 2-1. Groundwater level depths (metres below ground level) and electrical conductivity values (EC, milliSiemens per metre) for piezometers on 28 November 2000 and locations of cross-sections in Figures 2-2 to 2-5

2.2.2. Drilling methods

An 'air-core' drilling rig was used. Bit diameter was 125 mm and holes were cased with 50 mm-diameter class 18 PVC pipe immediately after completion of the hole. All piezometers were screened for 2 m at their bases using 0.5 mm slotted, 50 mm-diameter PVC pipe. The annuluses of the slotted sections were gravel-packed with '8x16' graded gravel (about 1.5 to 3.0 mm diameter) and a cement plug was installed above the gravel pack.

Installation of the PVC casing encountered some problems. The casing often became trapped within the inner tube and was pulled out of the ground as the drill string was removed. This was overcome by filling the casing with fresh water to add weight to the PVC string and allow removal of the rods.

2.2.3 Piezometer and production bore development

Development of the piezometers was performed approximately four weeks after construction. Development involved air-lifting with a small, portable compressor until the groundwater discharged was clear, or its clarity did not improve with time.

2.2.4 Drill sample descriptions

Composite samples were collected at one-metre intervals from a cyclone attached to the rig's sample hose. Some excellent samples of partly-weathered and fresh granitic bedrock were obtained. Field drill logs were completed at the time of drilling and are available at <http://www.agric.wa.gov.au/environment/links/RMtechreports/>.

2.2.5 Groundwater level monitoring and sample analyses

Groundwater levels were measured and water samples collected monthly until November 2000, and then at three-monthly intervals. 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.

2.2.6 Surveying

Sites were surveyed for position and height on 5 and 6 September 2000 using a dual frequency global positioning system. Standard survey practice was adopted, which was expected to produce accuracies of around ±20 mm horizontally and about ±50 mm for elevation.

2.3 Results

2.3.1 Profile descriptions

Detailed drill logs are available at <http://www.agric.wa.gov.au/environment/links/RMtechreports/> and the profiles are illustrated in the cross-sections in Figures 2-2 to 2-5.

The following summarises the components of the profiles drilled, from the top of the profile downwards:

- *colluvium* –sands, gravels, gravelly clays and sandy clays;
- *mottled zone* – minor occurrences of variably-coloured sandy clays; uncommonly included coarse to very coarse angular ferricrete and silcrete;
- *saprolite clays* – generally white, light brown and brown, sandy, light to medium clays, becoming more micaceous with depth;
- *saprolite grits* – clayey, with fine to very coarse, angular quartz and weathered granite;
- *bedrock* – hard, fresh granite rock, defined by depth of drill refusal.

Woodanilling townsite is on a biotite granite basement that varies in elevation throughout the town, cropping out on the north-eastern side (Figure 2-1). Bedrock was encountered at depths of about 6.5 m at 00BY08D, 10 m at 00BY09D and 12 m at 00BY07D on the northern side. On the eastern side at 00BY04D, bedrock was 9 m deep. The regolith was between 28 and 29 m deep at three sites, 00BY02, 00BY06 AND 00BY11, which lie on a line striking north-eastwards through the townsite, towards the southern tip of the rock exposure (Figure 2-1).

Overlying the granitic bedrock below most of the town was a residual 'saprolite clay' layer dominated by micaceous, kaolinitic clays containing fine-grained angular quartz. Drilling in the saprolite clays was easy and drill refusal against bedrock was abrupt. Below most of the town, the expected coarse, quartz-rich 'saprolite grits' layer was either thin or absent. All boreholes were low-yielding.

2.3.2 Groundwater data

Piezometer and groundwater details are listed in Appendix 1 and the changes in groundwater level and EC values across the townsite are shown in Figure 2-1.

Groundwater level depths ranged from about 13 m below ground at site 00BY06, near the exposed rock in the north-east of the townsite, to only 1 m below ground level at site 00BY01 (the nearest site to the Boyerine Creek). Groundwater levels were also shallow (between about 1.5 and 2.5 m deep) at site 00BY10, on the western edge of the town. The groundwater level elevations only ranged between about 277.5 and 281.5 m above Australian Height Datum (AHD). They fell from south-east to north-west. At sites where there were both deep and shallow piezometers, differences in groundwater level elevations were small (within 0.2 m).

Groundwater EC values at most sites ranged between about 1500 and 3000 mS/m, and increased downslope from the rock exposure in the north-east of the townsite. However, in piezometer 00BY09M, values were only around 900 mS/m, and the salinity of the groundwater in the deeper piezometer at that site was also relatively low (about 1500 mS/m). At other sites with nested piezometers: the EC values at the two depths were similar (sites 00BY01 and 00BY02); the deeper piezometer had slightly higher EC values (at sites 00BY10 and 00BY11); or the deeper piezometer had slightly lower EC values (at site 00BY05).

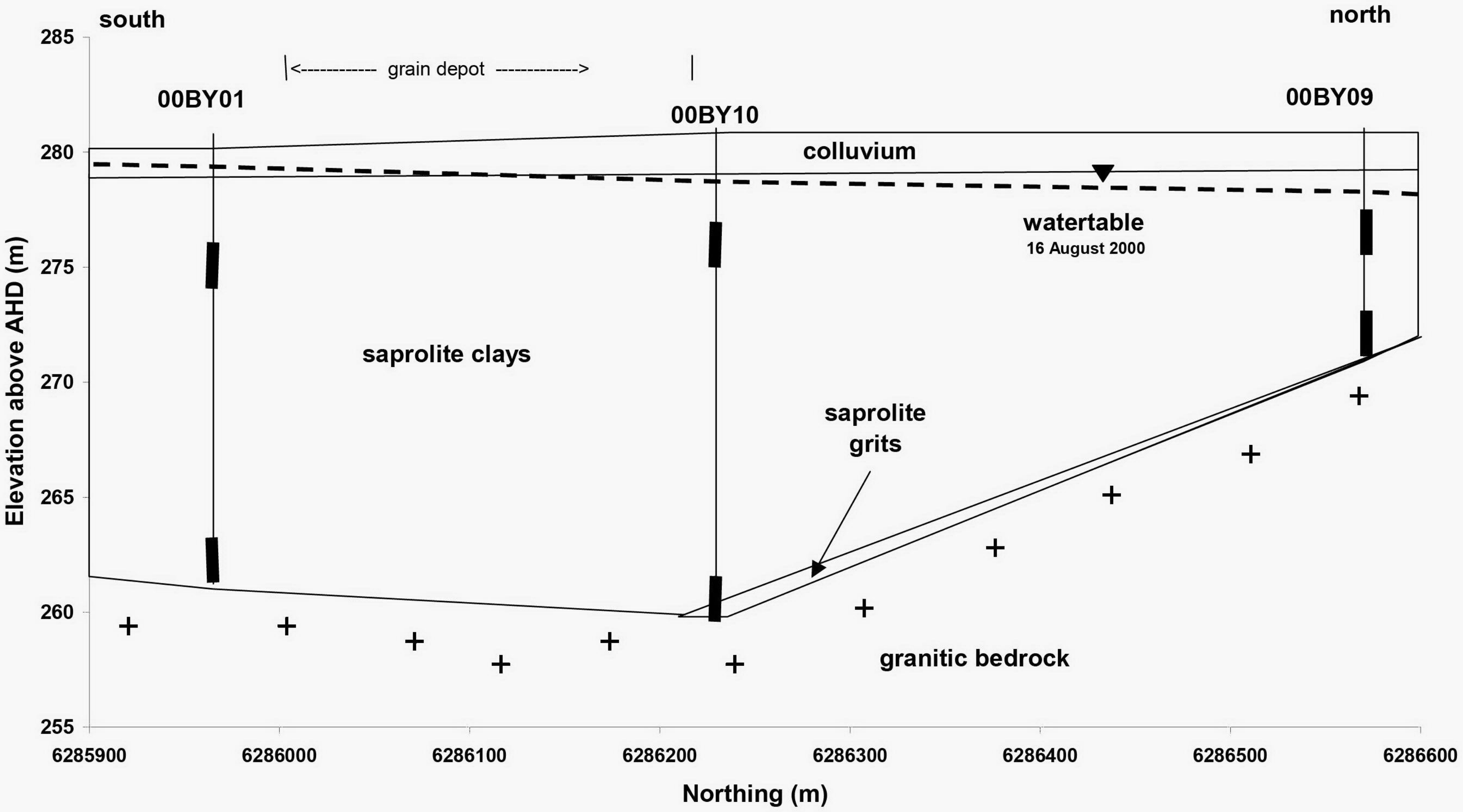

Figure 2-2: South to north cross-section through sites 00BY01, 00BY10 and 00BY09 (location shown in Figure 2-1; locations of lithology boundaries between drilled sites are inferred)

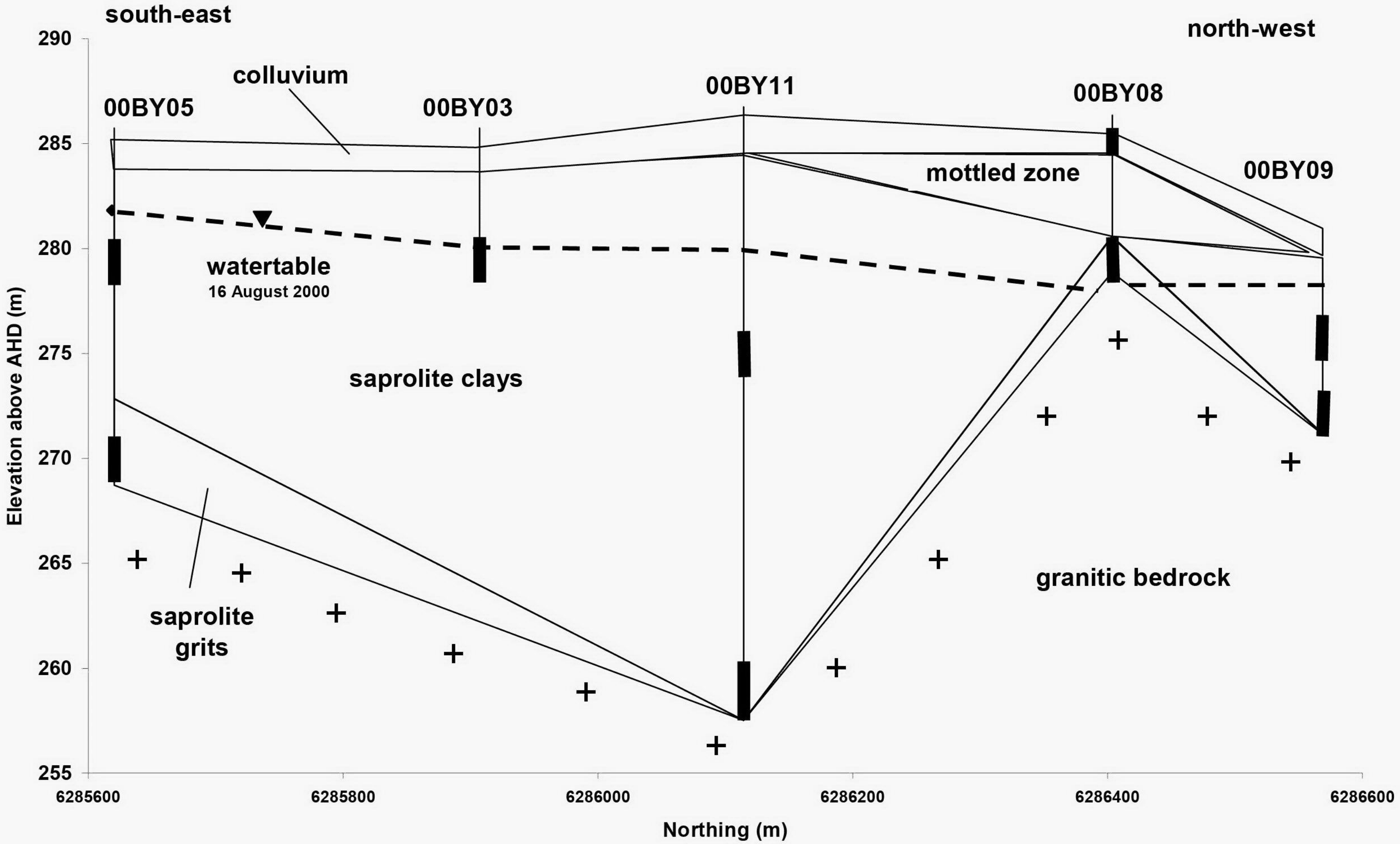

Figure 2-3. South-east to north-west cross-section through sites 00BY05, 00BY03, 00BY11, 00BY08 and 00BY09 (location shown in Figure 2-1, locations of lithology boundaries between drilled sites are inferred)

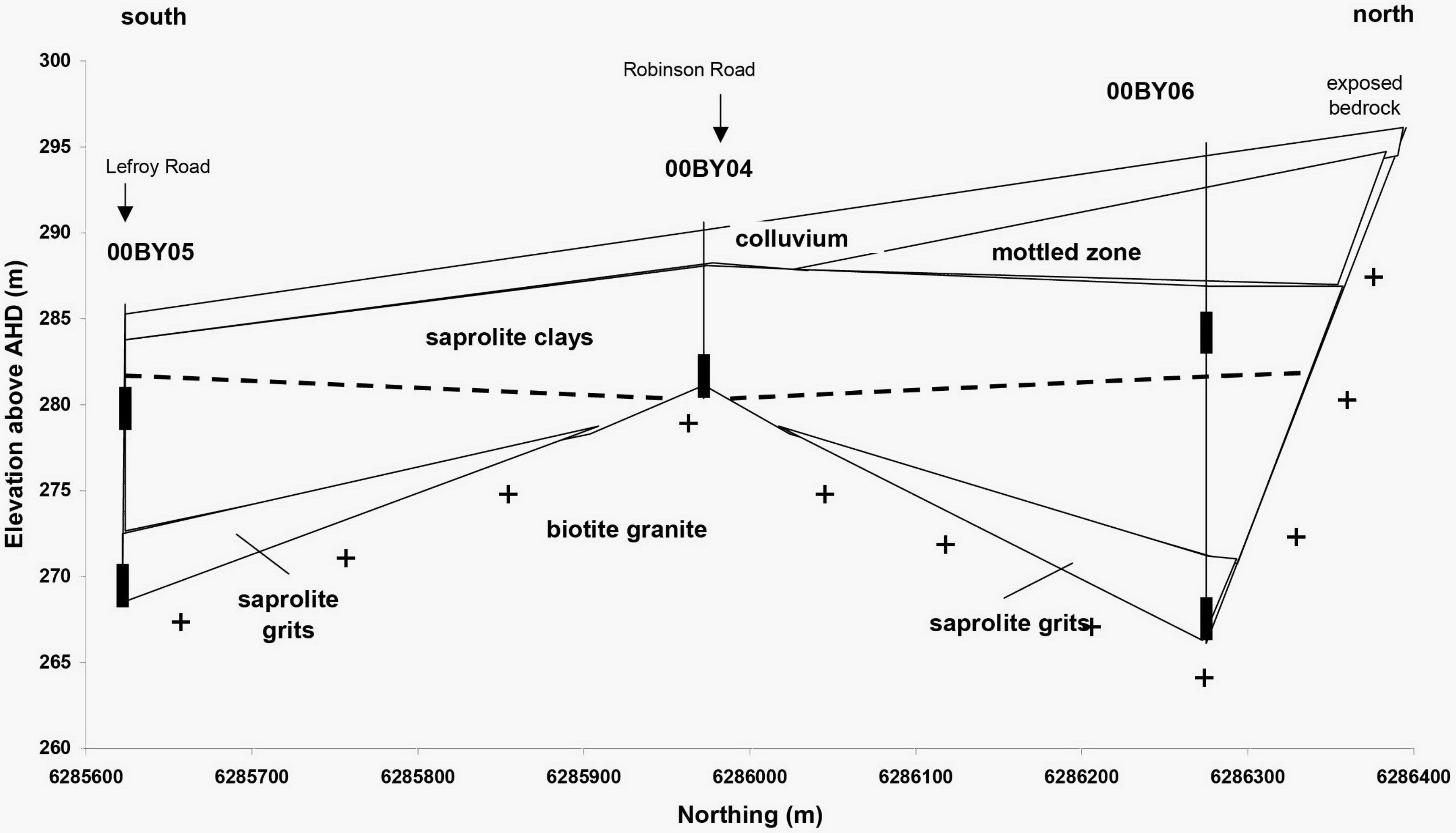

Figure 2-4. South to north cross-section through sites 00BY05, 00BY04 and 00BY06 (location shown in Figure 2-1, locations of lithology boundaries between drilled sites are inferred)

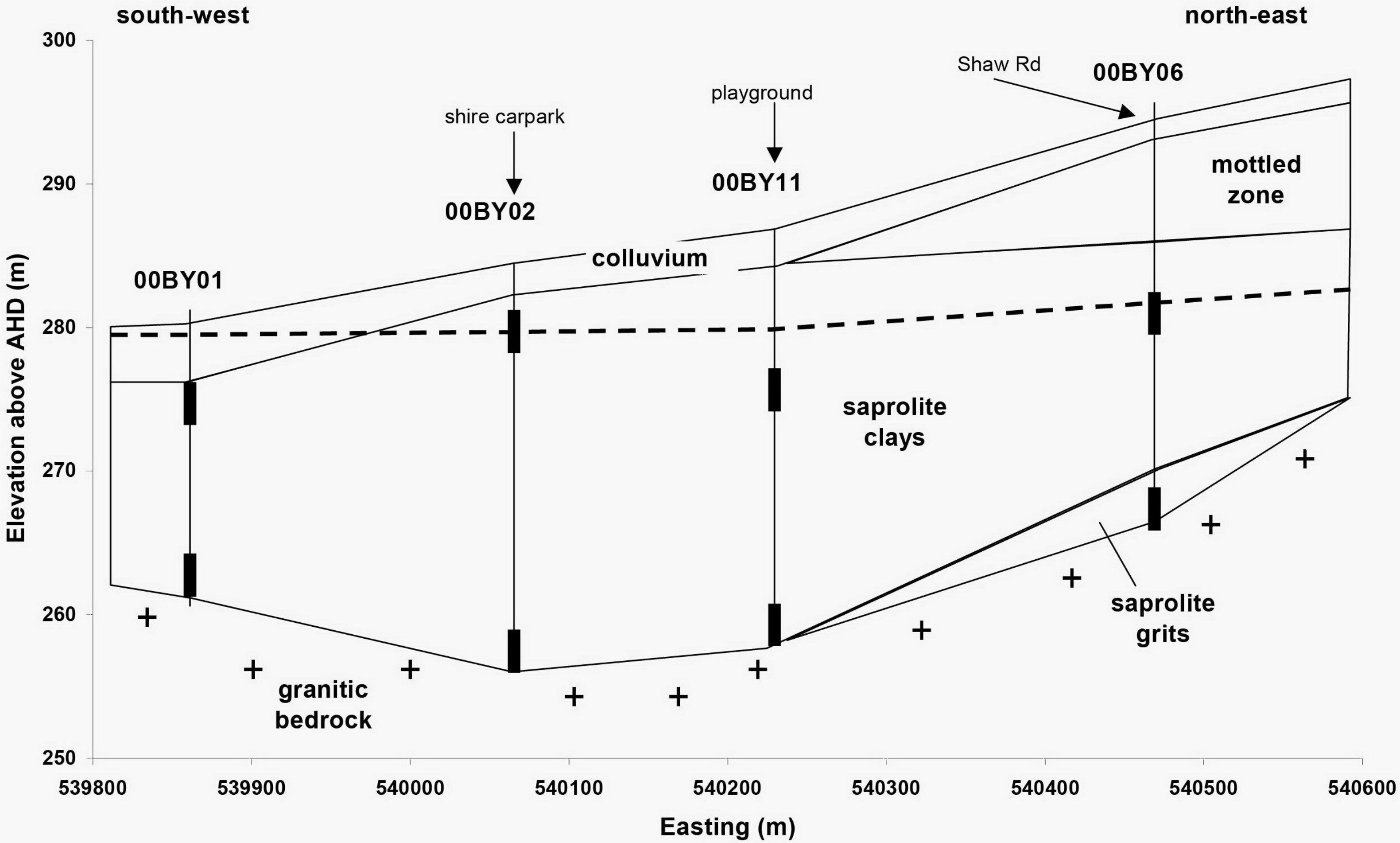

Figure 2-5. South-west to north-east cross-section through sites 00BY01, 00BY02, 00BY11 and 00BY06 (location shown in Figure 2-1, locations of lithology boundaries between drilled sites are inferred)

2.4 Interpretation and discussion

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

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 Woodanilling.

2.4.1 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 high valley groundwater levels may 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 contribute.

2.4.2 Woodanilling recharge zones and groundwater flow

For this discussion, the townsite zone is considered to be the main built-up area, extending east from the Boyerine Creek; the upslope zone is the land above the town to its east; and the downslope zone is the section of the valley floor of the Boyerine Creek west and south of the townsite.

No measurements of recharge have been made in or around the Woodanilling townsite. Possible sources of recharge within the ***townsite zone*** are rainfall, supplies brought in for residents to use, and surface water flowing in as run-off from up-slope areas. There is not yet enough groundwater level information to tell when and where most recharge occurs. However, since groundwater elevations below the slopes in the east of the town are higher than those to the west and south, the implication is that some recharge does occur below the town's slopes.

There is also a lack of information on recharge in the other two zones (the ***upslope zone*** to east, and the ***downslope zone*** to the south and west). However, the land around the town is under agriculture, so recharge in these zones was assumed to be high. If the groundwater flow below the upslope zone follows the fall of the land surface, then most inflow to the townsite zone would occur through the southern part of the eastern town boundary.

The Boyerine catchment extends at least 10 km (Figure 1-1) to the south of Woodanilling, and so a large area of land contributes surface flows to the ***downslope zone*** (some of which could become recharge in that zone). However, areas of groundwater discharge and salinity can be seen along the creekline to the south of Woodanilling, which suggests that groundwater flow down the catchment is inhibited in some places. Therefore, it was assumed that the groundwater system of the ***downslope zone*** receives groundwater inflows from only the closer parts of the Boyerine surface water catchment. Salinity along the creekline indicates that groundwater levels below the downslope zone are high, and these high levels are expected to inhibit groundwater outflow from the townsite zone. The form of the land also suggests that the high watertables in the east and south of the townsite zone are at least partly the result of groundwater rises spreading from the valley floor zone, rather than solely from the accumulation of groundwater from the townsite zone.

Drilling showed that the bedrock below three sites (00BY06, 00BY11 and 00BY02) sitting on a line heading south-west from the southern end of the exposure of rock (Figure 2-1) was deeper than elsewhere. These sites also follow the line of a subtle shallow gully. The line of deep regolith may trace the path of a fault. As site 00BY06 is close to the exposed rock, the implication is that the bedrock to the north was displaced upwards relative to that to the south. However, there is not enough data available to determine whether the zone of deep regolith is associated with either groundwater barrier or groundwater carrier effects.

The surface topography (Figure 1-2) shows spurs on the eastern and western flanks of the catchment restrict the width of the valley floor near the north of the townsite zone. The spurs are assumed to represent zones of bedrock that are relatively resistant to weathering, or zones that have been displaced upwards relative to the bedrock to the north and south. It is likely that the groundwater systems that have developed in the regolith below the valley floor are similarly reduced in width, and possibly depth, in the northern part of the town. This is supported by the relatively shallow bedrock below sites 00BY08 (Figure 2-3) and 00BY09 (Figure 2-2). Such constriction would limit the volume of groundwater outflow to the north.

In summary, it appears that the groundwater systems below the valley floor zone are important in controlling the high groundwater levels below the west and south of the townsite, but that recharge within the townsite and the slopes to the east contribute to these high levels. Long-term frequent and regular monitoring of groundwater levels in the piezometer network can show where the important recharge areas within the townsite are, and when they are active. This will help to establish whether rain is a more important contributor than imported water supplies within the townsite over the long-term. However, the groundwater system below the downslope zone is also fed by recharge below agricultural land in the surrounding catchment.

2.4.3 Assessment of salinity risk

It is not known whether groundwater levels below Woodanilling are stable or rising, since there are no long-term groundwater level records for the town. Since it appears that groundwater outflow north along the valley floor is restricted (Section 2.4.2), it is possible that the groundwater system below the valley floor is gradually 'filling up', in which case, salinity would spread upslope into the townsite. However, it is also possible that groundwater levels have already risen to heights at which they are stable (apart from seasonal fluctuations).

Regular and frequent monitoring of the piezometer network over the long-term will indicate if groundwater levels are rising, and if the zone with shallow groundwater levels is likely to expand.

2.5 Management options

Options for managing problems caused by shallow groundwater involve both recharge reduction and groundwater abstraction.

2.3.2 Recharge reduction

There are usually more opportunities for town communities to reduce recharge below their townsite than below the surrounding agricultural land. 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, pools, areas where run-off accumulates and ponds, bare soil areas, and septic systems or sewage ponds. Some methods of reducing recharge have other benefits (e.g. reduced water supply costs, less waste of rainfall, less infrastructure damage from surface water). Ways to reduce recharge within the townsite 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. Groundwater monitoring should continue following any changes, to assess their impacts.

2.5.2 Groundwater abstraction

When ground conditions are suitable, groundwater drainage and groundwater pumping from bores can lower shallow groundwater levels below large areas. However, groundwater abstraction is expensive, may cause settlement damage to buildings and infrastructure, and the abstracted groundwater has to be carefully used or evaporated to avoid causing problems elsewhere. Since the groundwater abstraction has to continue as long as lowered groundwater levels are required, long-term maintenance has to be taken into account.

The groundwater systems around Woodanilling are likely to be compartmentalised because there are zones of resistant bedrock, and these could form groundwater barriers. Groundwater pumping is not a useful approach to lower groundwater levels in such environments, as the drawdown effects are limited to small areas. Similarly, groundwater drainage is usually only effective for areas close to the drain. Either option would need careful and thorough investigation before being implemented.

3. Groundwater flow modelling

Author: Jay Matta (Agriculture Western Australia)

This section describes a computer groundwater modelling study that aimed to assess the impacts of a selection of possible strategies.

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).

A suitable conceptual model was constructed based on the information gained from the drilling investigation with topographic and climatic data. This conceptualisation was adapted to the groundwater simulation program MODFLOW (McDonald and Harbaugh 1988) coupled with the pre- and post-processor PMWIN version 5.0 (Chiang and Kinzelbach 1998) and was calibrated in steady-state against observed groundwater levels. The model was then used to simulate the effects of three different strategies: do nothing differently', groundwater abstraction by pumping, and revegetation.

Sections 3.1 and 3.2 describe the construction of the conceptual and computer models and calibration of the computer model. The strategy simulations and their results are presented in Section 3.3, and limitations are discussed in Section 3.4.

3.1 Model construction and conceptualisation

Conceptually, the groundwater model consisted of one layer, an unconfined residual granitic profile with high clay content and spatially disconnected thin lenses of 'saprolite grit'.

Inflow to the model domain, illustrated in Figure 3-1, was assumed to be through lateral flow from the south-eastern boundary of the townsite and outflow was assumed to be towards the north-west.

The model domain covered 0.7 km from east to west and 1 km from north to south. This incorporated most monitoring sites in the town. Each cell in the domain was 20 m by 20 m, resulting in 35 columns and 50 rows. The total number of cells was therefore 1750.

The top of the unconfined layer was taken to be the land surface, extracted from 2 m-contour digital elevation models for the catchment (map sheet 23301NE, Spatial Resource Information Group, Agriculture Western Australia). This information, with depths to bedrock, was taken from borehole logs, gridded and interpolated by kriging, and assigned to each model node. Both the south-eastern inflow and north-western outflow boundaries were simulated as general head boundaries. Due to parallel lines of equipotential running from inflow to outflow boundaries, the north-east and south-west boundaries were taken as no-flow boundaries.

Recharge was applied uniformly over the modelled area and set initially as 5 per cent of annual average rainfall, which was taken as 464 mm/year.

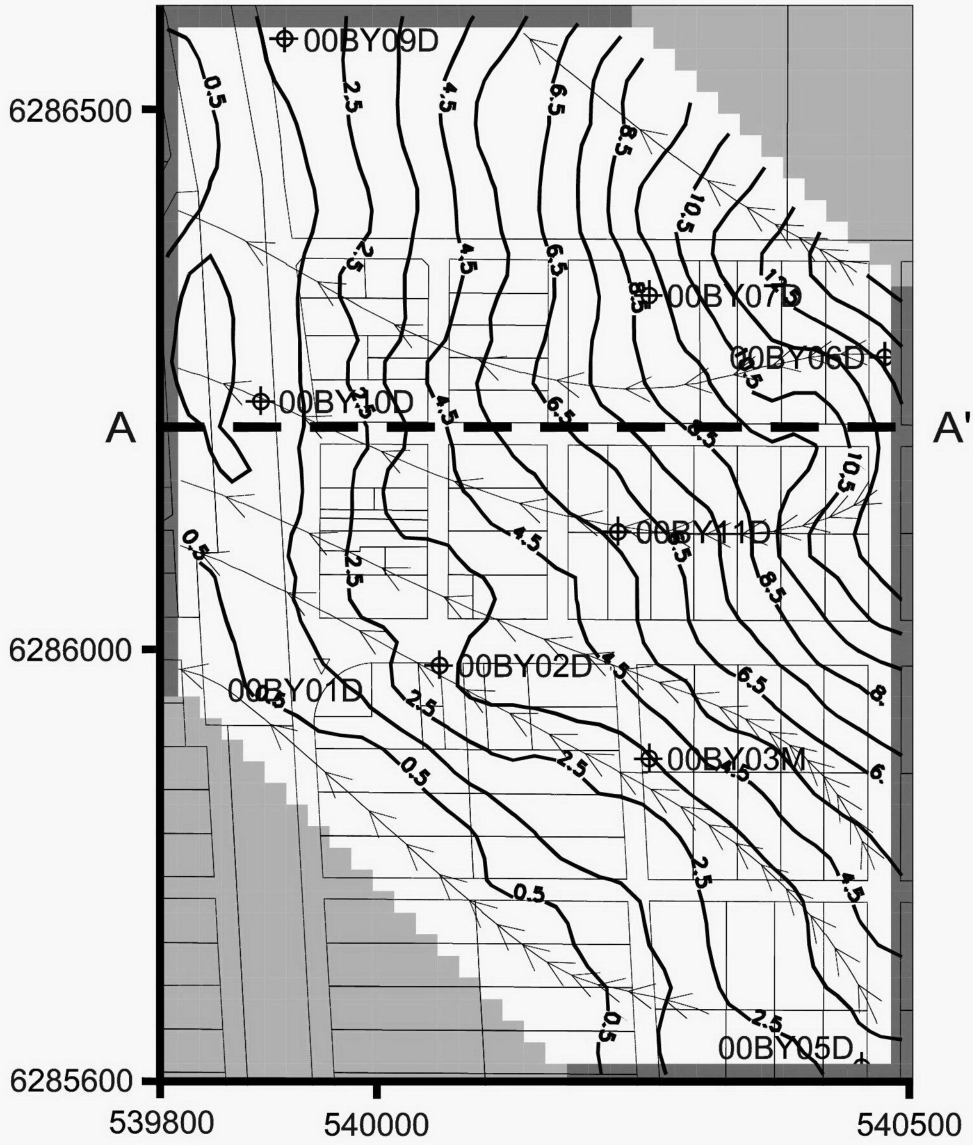

Figure 3-1. Modelled region with boundary conditions (dark lines around south-eastern margins represents an inflow boundary; dark lines around the north-western margins represent an outflow boundary), bore locations, modelled watertable contours (winter 2000) and flow lines for steady-state model (boundary scales are eastings and northings AGD84 in metres, watertable contours in metres below ground level)

3.2 Steady-state model calibration

Calibration of the steady-state model was accepted with a variance of 0.29 m between the modelled groundwater levels and those measured in September 2000 at all monitoring sites within the modelled area. The parameters used to achieve this are listed in Table 3-1. The hydraulic conductivity for the single layer was taken as spatially uniform. The variation in the variance between modelled and observed heads was greatest with changes in recharge and ultimately horizontal hydraulic conductivity. The calibrated recharge rate required to achieve the variance was approximately 4 per cent of annual rainfall or 19 mm/year. The resulting depths to the watertable for the calibrated model and travel paths are shown in Figure 3-1.

Travel times below the townsite varied from less than 10 years to a maximum of 250 years along the longer flow paths.

Table 3-1. Parameters used for the Woodanilling model

Parameter	Layer 1
Horizontal hydraulic conductivity (m/day)	0.75
Effective porosity	0.15
Recharge (mm/year)	19

3.3 Dynamic simulations of strategies

The dynamic simulations extended over 30-year periods. A specific yield of 0.15 was applied over the whole model domain. It was assumed that the watertable would rise at 0.1 m/year and this rate was applied to both inflow and outflow boundaries.

3.3.1 ‘Do nothing differently' strategy

The 'do nothing differently' scenario implies that no management of the system would take place and therefore the watertable would be recharged at the calibrated rate of 19 mm/year. The resulting watertable depth after 30 years is illustrated in Figure 3-2. The model predicted that under current management practices approximately 47 per cent of the active modelled area could eventually have a shallow watertable at 0.5 m or less from the ground surface. Those areas on the lower slopes of the town (the area close to the western boundary) would be at most risk.

3.3.2 Groundwater pumping 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 areas with groundwater levels 0.5 m or less from the ground surface and in the southern parts of the model domain. Given the low estimated groundwater yields, it was assumed that bores could produce up to 25 m^3/day. The bore field along the western margin of the active model domain had bores spaced up to a maximum of 140 m apart. Under the conditions modelled, the configuration shown in Figure 3-3 would reduce the area affected by shallow watertables (0.5 m or less below ground level) to 8 per cent of the model domain.

3.3.2 Revegetation strategy

Reduction of recharge through revegetation of vacant shire blocks was also tested in the model as a potential management option. It was assumed that the vegetation would only become effective in reducing the recharge after five years. It was also assumed that the recharge under these areas would be reduced to zero while in all other areas the recharge rate would remain the same (19 mm/year). The areas simulated as revegetated are shown in Figure 3-4. The modelled drawdown after 30 years is mapped in Figure 3-4. The model predicted that the area potentially at risk from shallow watertables of 0.5 m depth or less would be the same as in the ‘do nothing differently’ scenario (47 per cent).

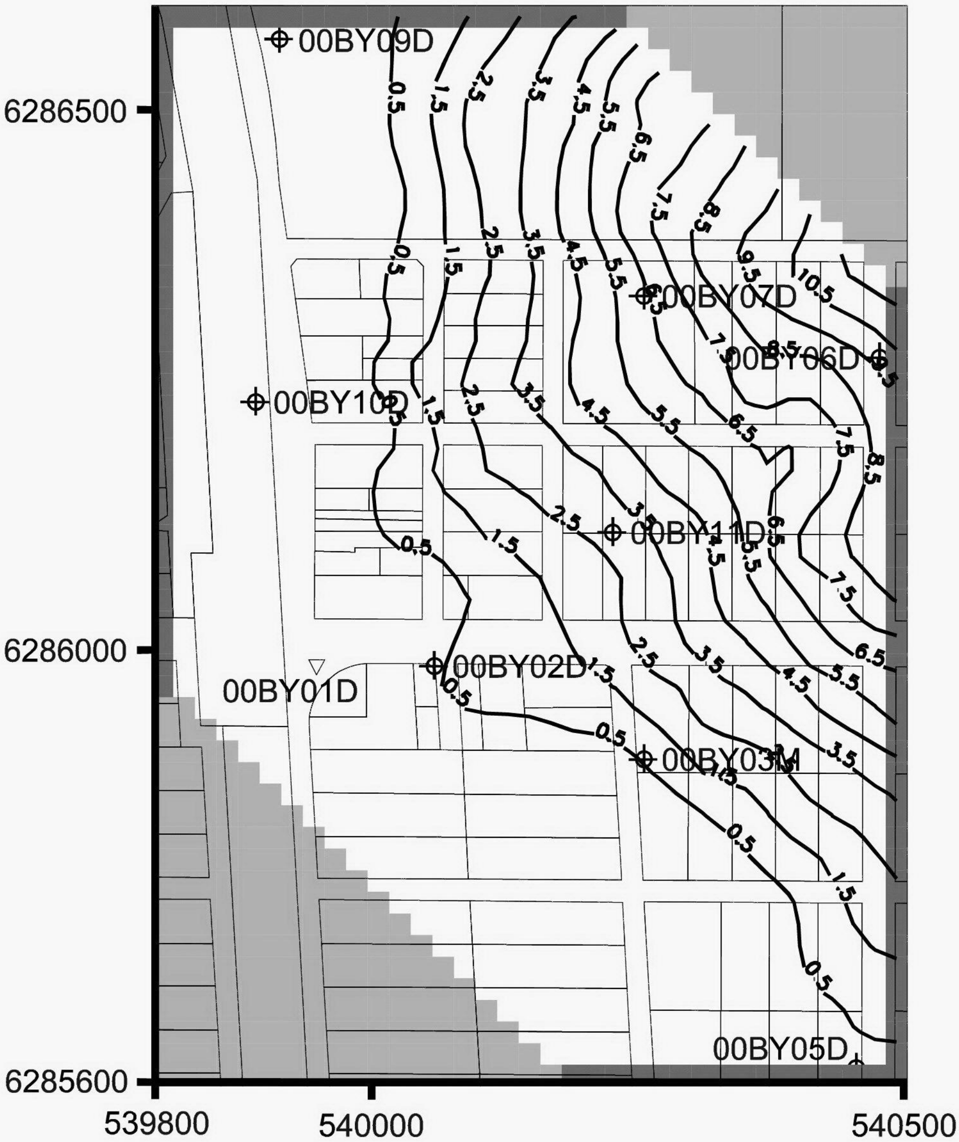

Figure 3-2. Modelled watertable depth below ground (in metres) after 30 years for the 'do nothing differently' simulation (boundary scales are eastings and northings AGD84 in metres)

3.4 Discussion of model

The groundwater modelling was undertaken using limited data and information:

- Models should be calibrated for several dates to cover the range of groundwater levels that occur. Because of limited groundwater level data, the model was only calibrated in steady-state against the 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 datasets. As no independent data were available, the model was not validated.

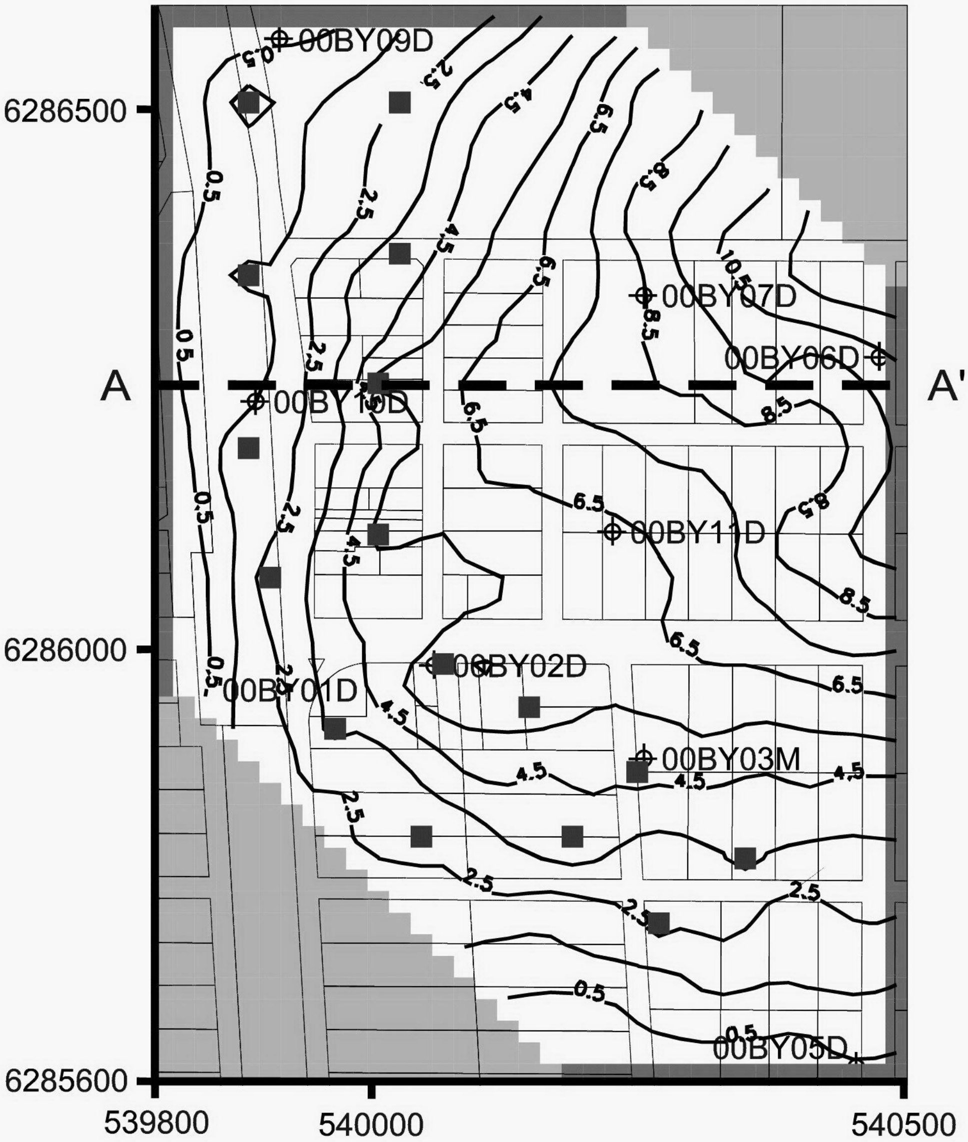

Figure 3-3. Modelled watertable depth below ground (in metres) after 30 years for the pumping simulation (boundary scales are eastings and northings AGD84 in metres)

- The model results are highly sensitive to both the recharge rate and values of hydraulic conductivity used, but the values used were only estimated from limited information or assumed.
- The model results are very dependent on DEM data (which represent 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 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.

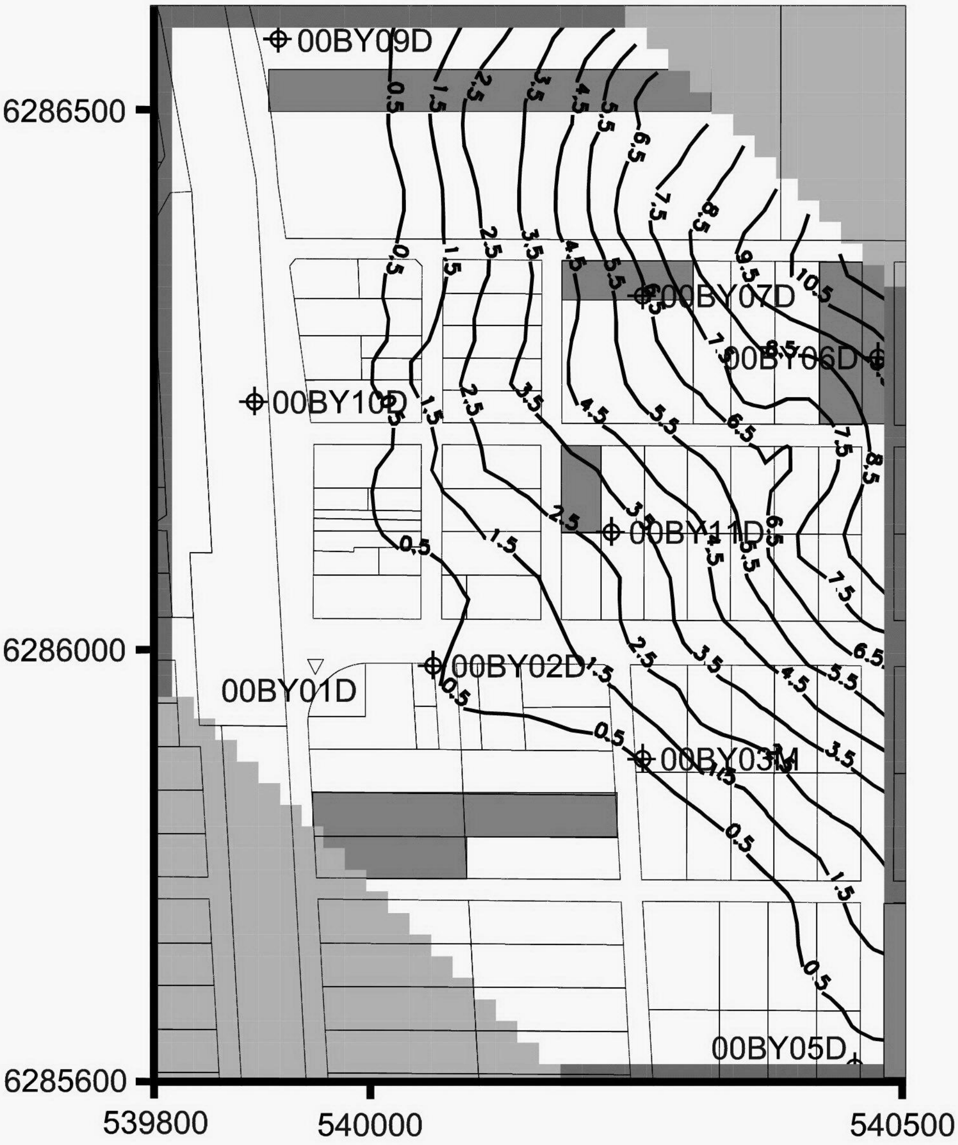

Figure 3-4. Modelled watertable depth below ground (in metres) after 30 years for the revegetation simulation (boundary scales are eastings and northings AGD84 in metres)

- Recharge was applied evenly across all of the modelled area, but in reality, it will vary spatially. No differentiation was made between bare areas or areas under annual and areas under perennial vegetation, irrigated areas, or areas with hard 'impermeable' surfaces. Since it is unvegetated areas and areas under annual plants which are likely to be replanted with perennial vegetation, the reduction in recharge is likely to be greater in reality than that assumed in the model. Therefore, revegetation is likely to be a more effective option than the model indicated.
- The model did not incorporate geological features that could act as groundwater barriers or carriers below the town.

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

4. Flood risk analysis

Authors: Muhammad J. Siddiqi and Ali Mahtab (Agriculture Western Australia)

In late January 1982, continuous rain caused local flooding throughout the south-west of Western Australia. The flood water levels in Woodanilling were slightly below those of the 1955 floods, even though exactly the same amount of rainfall (246 mm) was recorded. Some erosion damage and loss of fences were experienced. Much of the gullying of creeklines evident in the shire today resulted from the wet winter of 1945 (Bird 1985).

4.1 Objective of this study and approach

The objective of this part of the project was to determine the flood risk (high, moderate or low) to assess how frequently substantial volumes of flood water provided a potential source of groundwater recharge. This was done by calculating the peak flood flow generated by all of the catchment for the town (at a point just downstream of the townsite) and the run-off 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 for the town 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 peak flood flows were calculated for 2-, 5-, 10-, 20-, 50- and 100-year average recurrence intervals (ARIs) based on historical events. The run-off volumes generated by pervious and impervious (i.e. high run-off generating) surfaces within the townsites were calculated for 20-, 50-, and 100-year ARIs.

4.2 Input data

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

4.2.1 Available information

The following information was collated for Woodanilling:

- 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.

4.2.2 Derived information used in the calculations

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).

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 and how run-off volumes for the town catchment were estimated.

Run-off volumes were calculated separately for the 'pervious' parts of the town and for the 'impervious' (i.e. high run-off generating) areas using run-off coefficients of 0.1 for the former and 0.9 for the latter.

4.2.3 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 Woodanilling town catchment, parameters used for a calibrated model derived for Moora Townsite (Ali *et al*. 2001) were substituted.

4.3 Results

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

Table 4-1. Peak flood flow for the catchment for the town of Woodanilling

ARI (years)	Peak flood (m^3/s)
2	3.2
5	9.5
10	18.3
20	30.2
50	50.4
100	67.9

Table 4-2. Run-off volumes for pervious and impervious areas of the townsite generated by rainfalls of various ARIs, duration and intensities

Average recurrence interval (years)	**Rainfall duration (h)**	**Rainfall intensity (mm/h)**	**Rainfall (mm)**	**Run-off volume**	
				pervious area (m^3)	**impervious area (m^3)**
20	**1**	25.00	25.00	500	3,380
	6	7.70	46.20	920	6,240
	24	3.00	72.00	1,440	9,720
50	**1**	31.00	31.00	620	4,190
	6	9.50	57.00	1,140	7,700
	24	3.70	88.80	1,780	11,990
100	**1**	36.00	36.00	720	4,860
	6	11.00	66.00	1,320	8,910
	24	4.30	103.00	2,060	13,930

4.4 *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 flood flows for the catchment for 20-, 50- and 100-year ARIs for storms of 24 hours duration were compared to the catchment area, the accumulation potential of the catchment and the flow generated within the townsite. Table 4-3 shows the flood risk to the town of Woodanilling for 20-, 50- and 100-year ARI storm events of 24 hours duration.

Table 4-3. Flood risk to the Woodanilling townsite for 20-, 50- and 100-year ARI storm events of 24 hours duration

ARI (years)	**Peak flood flow for entire catchment (m^3/s)**	**Volume of flood generated by townsite (m^3)**	**Accumulation risk**	**Flood risk**	**Overall flood risk**
20	30.2	11160	Low	Low	Medium
50	50.4	13760	Low	Medium	
100	67.9	16000	Low	Medium	

4.5 Conclusion

Woodanilling is at overall low risk from flooding from storm events with up to 20-year ARIs and at medium risk from storms with 50- and 100-year ARIs. Localised flooding may be associated with rainfall events with ARIs greater than 50 years, but there is no threat for most of the town infrastructure, except any in relatively low-lying areas.

4.6 Warning

The peak flood flow and run-off values estimated in this report should not be used as inputs for the design of any engineering structures such as drains, culverts or diversion banks as the input parameters used for this study would not be suitable for such uses. It is recommended that for any specific use the peak flood 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

Groundwater levels are already shallow below low lying sites in the Woodanilling town. It is not known whether they are stable or rising. It was concluded that the main sources of the groundwater below the townsite were recharge occurring within the townsite and groundwater inflow from below the valley floor of the Boyerine Creek, upstream of the town. Some groundwater may also flow to the townsite from below the agricultural land to the east of the town. There are opportunities to reduce the recharge occurring within the townsite, and some of these would have additional benefits. A large reduction in recharge below the surrounding agricultural land would also improve the problem, but it was assumed that this would be more difficult to achieve. Because of the bedrock and regolith geology, groundwater abstraction would have only limited impacts on the watertable levels.

5.1 Recommendations

1. Adopt those methods of **reducing townsite recharge** that will also provide other benefits (see the suggestions in Section 2.5.1).

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.

6. Acknowledgments

The Woodanilling Shire participated and cooperated in the stages of this study. Jim Prince and Ed Solin (Agriculture Western Australia, South Perth) collected data for the hydrogeological investigation.

7. References

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Appendix 1. Piezometer and groundwater data

Table A1-1. Construction details for new piezometers (names begin with '00') and for pre-existing piezometers (names begin with '92')

Bore name	Easting AGD84[#] (m)	Northing AGD84[#] (m)	Elevation of top of casing above AHD[##] (m)	Casing total length (m)	Height of casing above ground level (m)
92BY01M	539959.7	6285925.9	281.0	8.53	
92BY01S	539960.7	6285925.1	281.1	2.23	
00BY01D	539850.1	6285966.6	280.0	18.14	0.78
00BY01M	539849.7	6285967.6	280.0	6.14	0.40
00BY02D	540060.9	6285990.6	284.4	6.54	0.44
00BY02M	540060.8	6285990.2	284.4	28.47	0.43
00BY03M	540255.8	6285903.9	284.9	6.44	0.33
00BY04D	540456.4	6285973.0	290.0	9.98	0.28
00BY05D	540452.6	6285618.7	285.2	16.79	0.62
00BY05M	540453.1	6285618.5	285.0	6.4	0.38
00BY06D	540474.2	6286276.8	294.4	29.5	0.37
00BY06I	540473.3	6286276.6	294.6	12.23	0.88
00BY07D	540255.6	6286332.3	290.4	12.32	0.56
00BY08D	540087.4	6286401.8	285.5	6.34	0.79
00BY08S	540087.2	6286402.6	284.8	3.14	0.14
00BY09D	539918.4	6286569.6	280.8	9.9	0.16
00BY09M	539918.7	6286568.9	281.1	6.16	0.56
00BY10D	539896.4	6286233.7	280.7	20.68	0.24
00BY10M	539896.4	6286233.0	280.9	5.89	0.45
00BY11D	540226.6	6286114.6	286.5	11.88	0.42
00BY11I	540226.1	6286113.9	286.7	27.72	0.68

#: Australian Geodetic Datum 1984; ##: Australian Height Datum

Table A1-2. Groundwater level depths for five dates

Bore name	Groundwater level depth below ground level (m)				
	30/6/00	2/8/00	5/9/00	5/10/00	28/11/00
	(m)	(m)	(m)	(m)	(m)
00BY01D	1.48	0.78	0.65	0.64	1.00
00BY01M	1.70	0.91	0.58	0.77	1.20
00BY02D	5.39	4.91	4.81	4.75	4.98
00BY02M	5.47	4.94	4.54	4.45	4.70
00BY03M	5.15	4.86	4.54	4.35	4.51
00BY04D	DRY	DRY	DRY	DRY	DRY
00BY05D	3.97	3.61	3.31	3.14	3.37
00BY05M	4.03	3.68	3.27	3.56	3.33
00BY06D	12.80	12.78	12.88	13.02	12.95
00BY06I	DRY	DRY	DRY	DRY	DRY
00BY07D	10.48	10.45	10.37	10.33	10.32
00BY08D	DRY	DRY	DRY	DRY	DRY
00BY08S	DRY	DRY	DRY	DRY	DRY
00BY09D	3.03	2.63	2.29	2.22	2.48
00BY09M	3.22	2.74	2.34	2.25	2.58
00BY10D	2.49	1.95	1.65	1.62	1.89
00BY10M	2.70	2.17	1.80	1.82	2.10
00BY11D	6.80	6.76	6.72	6.67	6.69
00BY11M	6.74	6.70	6.56	6.52	6.56

Table A1-3. Groundwater level elevations above Australian Height Datum (AHD) for five dates

Bore name	Groundwater level elevations above AHD (m)				
	30/6/00	2/8/00	5/9/00	5/10/00	28/11/00
	(m)	(m)	(m)	(m)	(m)
00BY01D	278.2	278.9	279.0	279.0	278.6
00BY01M	277.9	278.7	279.0	278.8	278.4
00BY02D	278.6	279.1	279.2	279.2	279.0
00BY02M	278.5	279.1	279.5	279.5	279.3
00BY03M	279.4	279.7	280.0	280.2	280.0
00BY04D	DRY	DRY	DRY	DRY	DRY
00BY05D	280.7	281.0	281.3	281.5	281.3
00BY05M	280.6	281.0	281.4	281.1	281.3
00BY06D	281.2	281.2	281.1	281.0	281.1
00BY06I	DRY	DRY	DRY	DRY	DRY
00BY07D	279.3	279.4	279.4	279.5	279.5
00BY08D	DRY	DRY	DRY	DRY	DRY
00BY08S	DRY	DRY	DRY	DRY	DRY
00BY09D	277.6	278.0	278.3	278.4	278.1
00BY09M	277.4	277.8	278.2	278.3	278.0
00BY10D	277.9	278.5	278.8	278.8	278.5
00BY10M	277.7	278.2	278.6	278.6	278.3
00BY11D	279.3	279.3	279.4	279.4	279.4
00BY11M	279.3	279.3	279.5	279.5	279.5

Table A1-4. Groundwater electrical conductivity values for five dates

Bore name	Groundwater electrical conductivity (mS/m)				
	30/6/00	2/8/00	5/9/00	5/10/00	28/11/00
00BY01D	70	2560	2570	2540	2700
00BY01M	2620	2590	2590	2550	2700
00BY02D	70	90	2600	2570	2740
00BY02M	2450	2550	2560	2530	2770
00BY03M	2940	2960	2980	2990	3360
00BY04D	DRY	DRY	DRY	DRY	DRY
00BY05D	60	70	2170	2150	2270
00BY05M	2480	2610	2670	2890	3240
00BY06D	50	60	1800	1810	1870
00BY06I	DRY	DRY	DRY	DRY	DRY
00BY07D	180	290	1190	1470	1610
00BY08D	DRY	DRY	DRY	DRY	DRY
00BY08S	DRY	DRY	DRY	DRY	DRY
00BY09D	1140	1180	1530	1540	1620
00BY09M	950	970	950	920	890
00BY10D	2600	2560	2570	2540	2690
00BY10M	2180	1700	2120	2070	2580
00BY11D	60	60	2250	2230	2350
00BY11M	270	280	1900	1840	1920

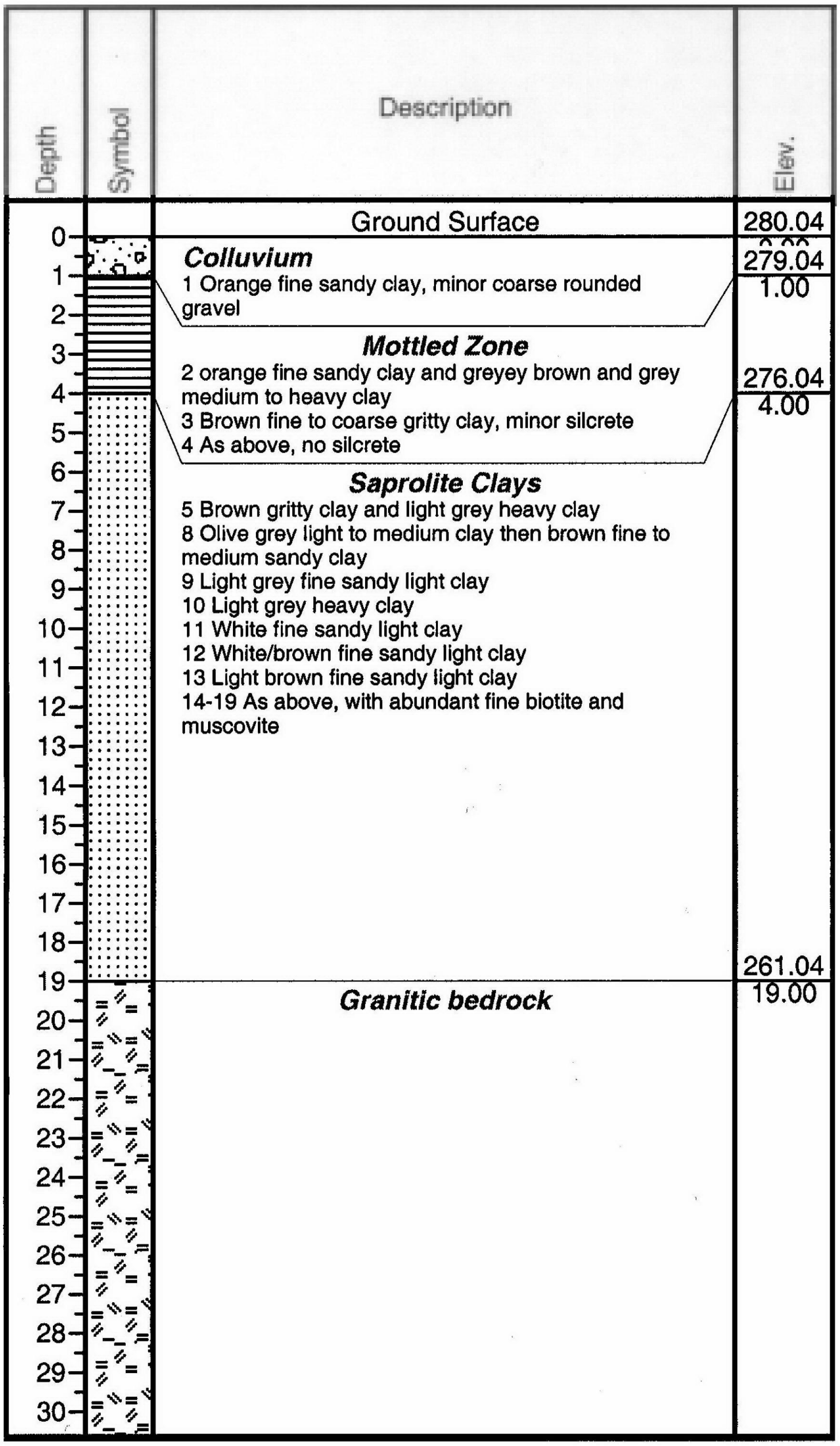
Appendix 2: Drill log results

Borehole: 00BY01D

Project:

Date: **Easting/Northing:** 539850.11 / 6285966.58

Location: **Hydrologist/ Supervisor:**



Ground Surface

Colluvium

1 Orange fine sandy clay, minor coarse rounded gravel

Mottled Zone

2 orange fine sandy clay and greyey brown and grey medium to heavy clay
3 Brown fine to coarse gritty clay, minor silcrete
4 As above, no silcrete

Saprolite Clays

5 Brown gritty clay and light grey heavy clay
8 Olive grey light to medium clay then brown fine to medium sandy clay
9 Light grey fine sandy light clay
10 Light grey heavy clay
11 White fine sandy light clay
12 White/brown fine sandy light clay
13 Light brown fine sandy light clay
14-19 As above, with abundant fine biotite and muscovite

Granitic bedrock

Casing Above Ground Level: 0.76, Medium 0.39

Casing Total Length: 18.14, medium 6.14

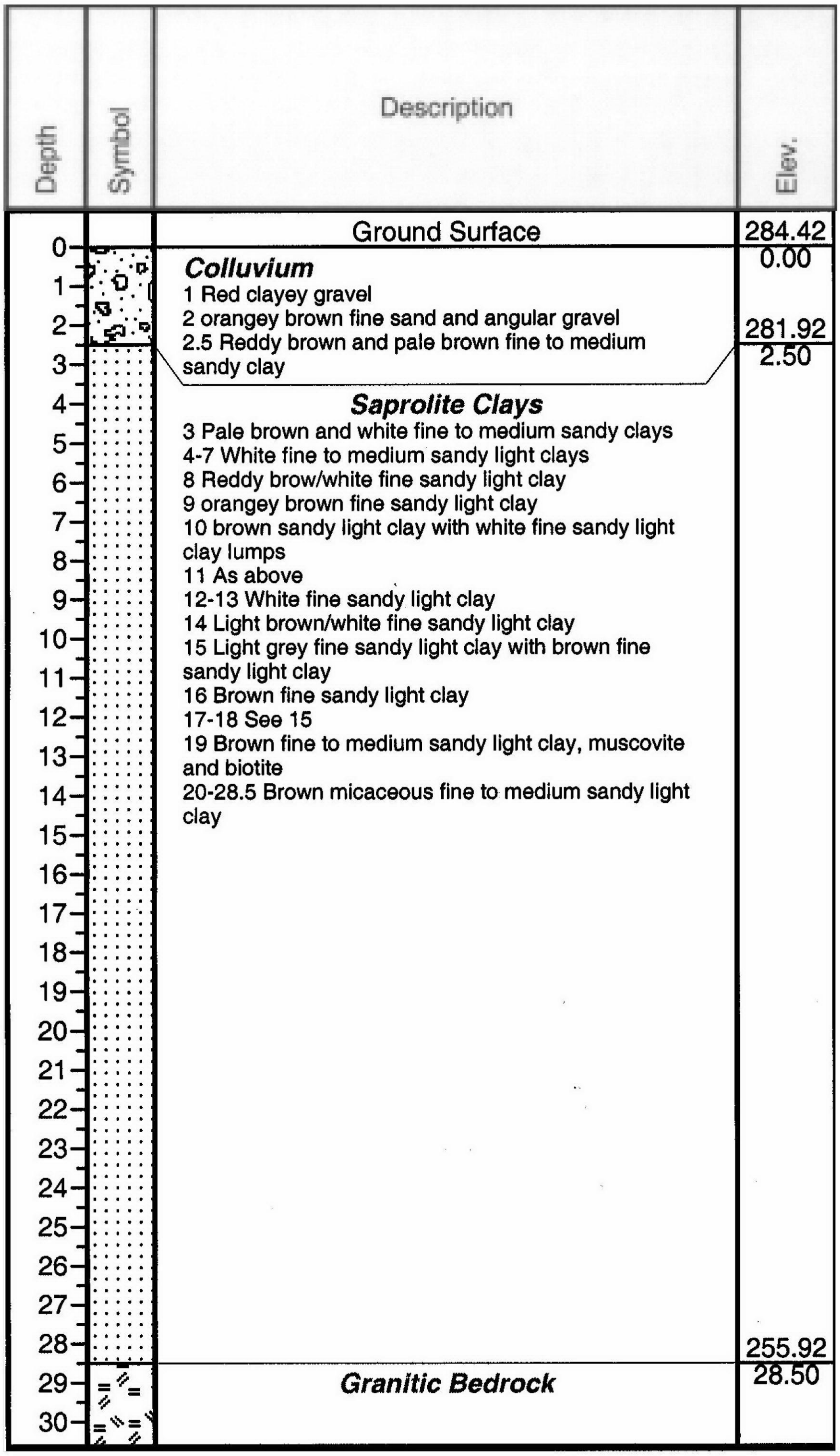
Screen: 2.0

Borehole: 00BY02D

Project:

Date: **Easting/Northing:** 540060.9 / 6285990.6

Location: **Hydrologist/ Supervisor:**



Ground Surface

Colluvium

1 Red clayey gravel
2 orangey brown fine sand and angular gravel
2.5 Reddy brown and pale brown fine to medium sandy clay

Saprolite Clays

3 Pale brown and white fine to medium sandy clays
4-7 White fine to medium sandy light clays
8 Reddy brow/white fine sandy light clay
9 orangey brown fine sandy light clay
10 brown sandy light clay with white fine sandy light clay lumps
11 As above
12-13 White fine sandy light clay
14 Light brown/white fine sandy light clay
15 Light grey fine sandy light clay with brown fine sandy light clay
16 Brown fine sandy light clay
17-18 See 15
19 Brown fine to medium sandy light clay, muscovite and biotite
20-28.5 Brown micaceous fine to medium sandy light clay

Granitic Bedrock

Casing Above Ground Level: 0.43, medium 0.36
Casing Total Length: 28.47, medium 6.54
Screen: 2.0

Borehole: 00BY03M

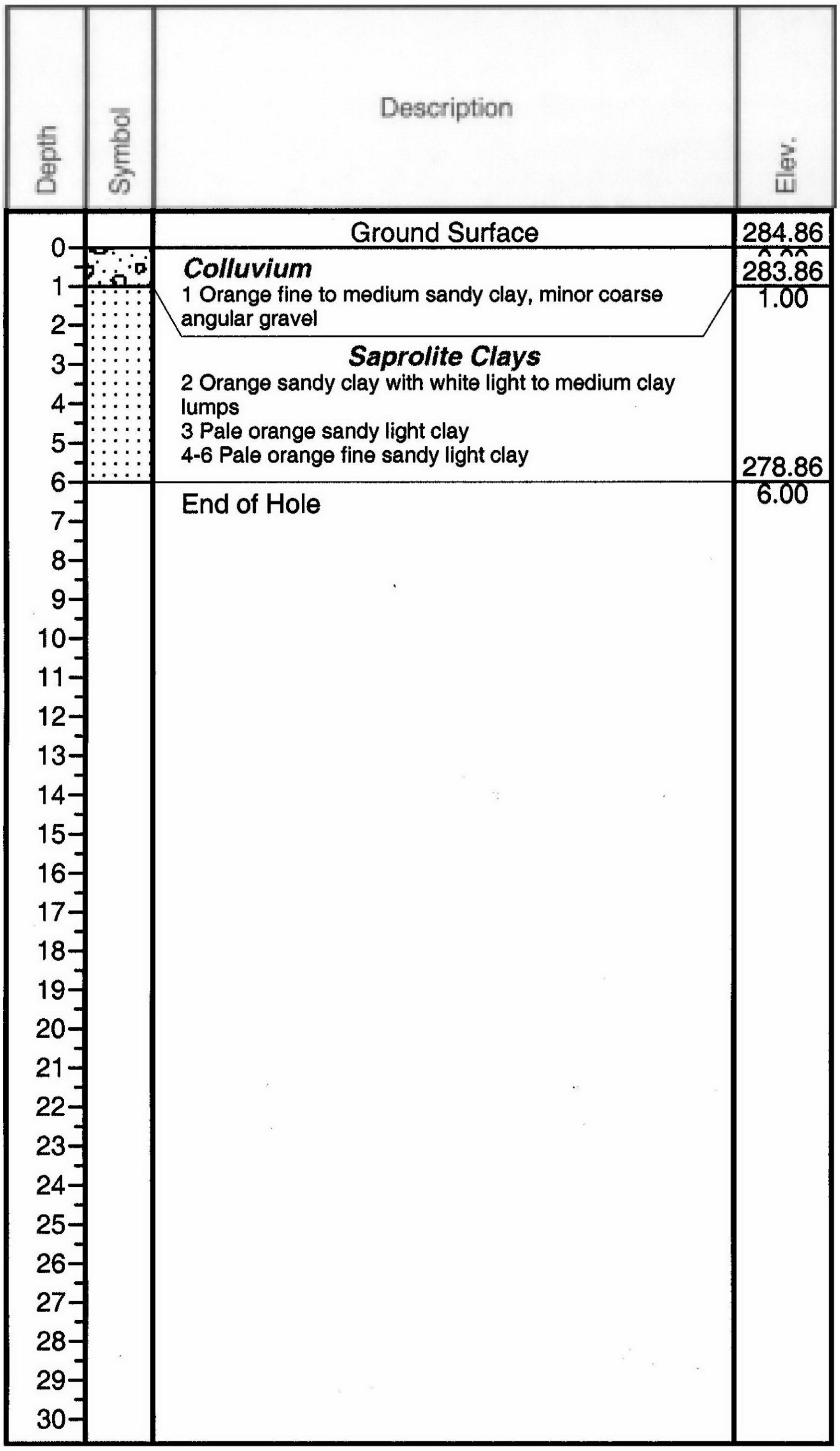
Project:

Date:

Location:

Easting/Northing: 540255.8 / 6285903.9

Hydrologist/ Supervisor:



Ground Surface 284.86

Colluvium 283.86 / 1.00

1 Orange fine to medium sandy clay, minor coarse angular gravel

Saprolite Clays 278.86 / 6.00

2 Orange sandy clay with white light to medium clay lumps

3 Pale orange sandy light clay

4-6 Pale orange fine sandy light clay

End of Hole

Casing Above Ground Level: 0.32

Casing Total Length: 6.44

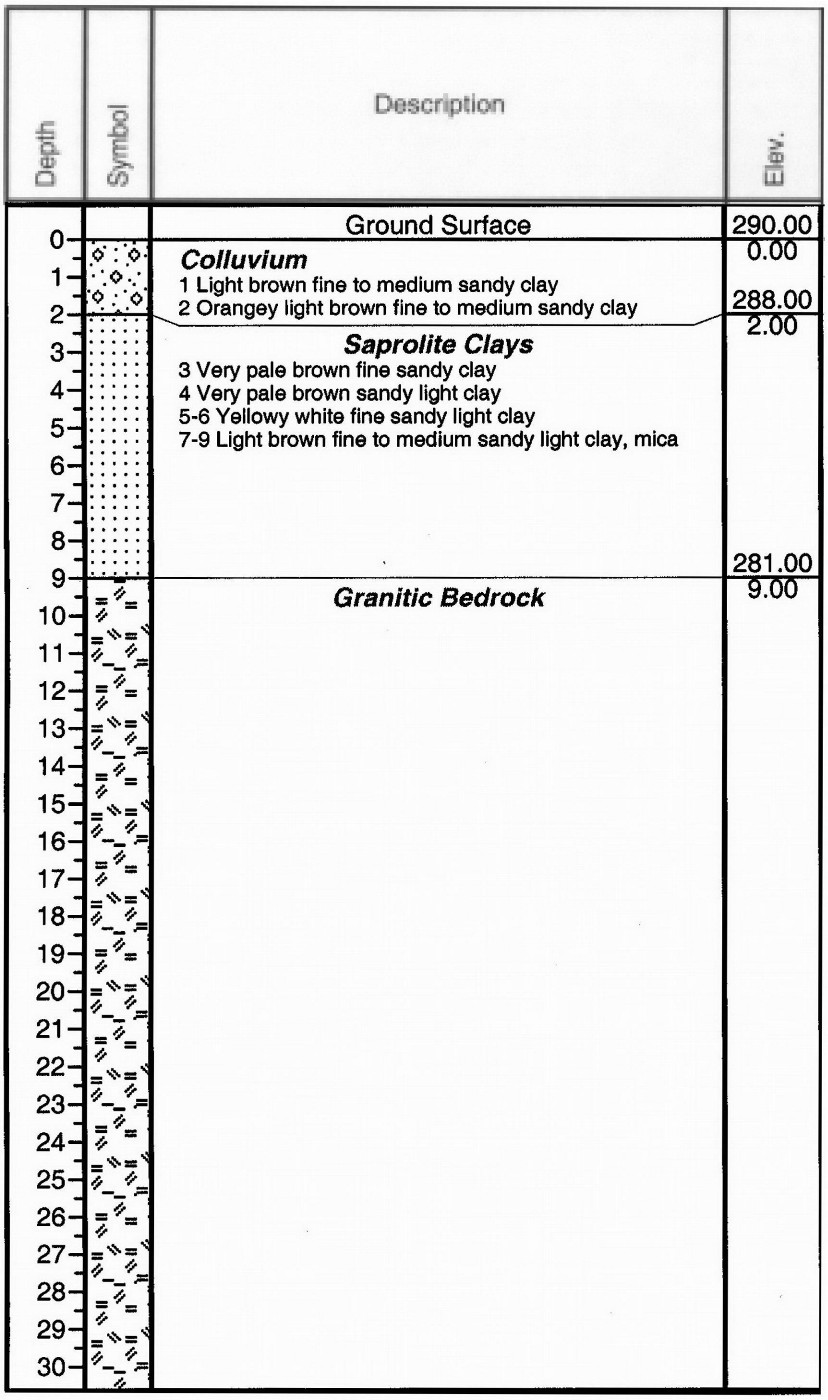
Screen: 2.0

Borehole: 00BY04D

Project:

Date: **Easting/Northing:** 540456.4 / 6285973

Location: **Hydrologist/ Supervisor:**



Ground Surface

Colluvium

1 Light brown fine to medium sandy clay
2 Orangey light brown fine to medium sandy clay

Saprolite Clays

3 Very pale brown fine sandy clay
4 Very pale brown sandy light clay
5-6 Yellowy white fine sandy light clay
7-9 Light brown fine to medium sandy light clay, mica

Granitic Bedrock

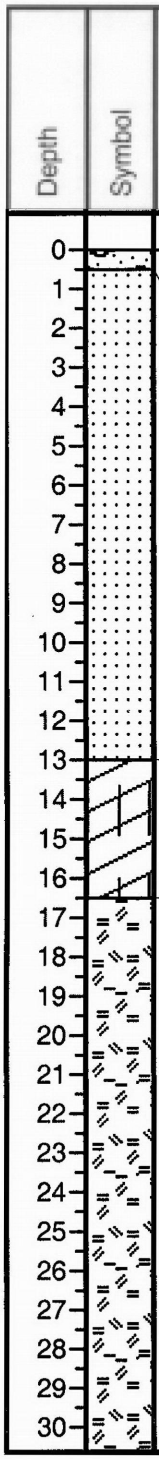
Casing Above Ground Level: 0.23
Casing Total Length: 9.98
Screen: 2.0

Borehole: 00BY05D

Project:

Date: **Easting/Northing:** 540452.6 / 6285618.7

Location: **Hydrologist/ Supervisor:**



Description	Elev.
Ground Surface	285.25
Colluvium 0.5 Gravelly fine to medium sand	0.00
Saprolite Clays 1 Very pale brown fine to medium sandy clay 2 Pale brown fine to medium sandy clay, coarse hard brown clay lumps 3 Brown fine to medium sandy clay and grey fine sandy light to medium clay 4 As above, orangey brown sandy clay and sandy light ot medium clay 5 orange/pinky orange sandy clay amnd white fine sandy clay 6 orange sandy clay and hard (breakable) micaceous sandy clay 7 Light brown fine sandy light clay and mica 8-9 Orange then white/grey fine sandy light clay and mica 10-13 Light brown sandy light clay, abundant mica	272.25
Saprolite Grits 14 Light brown fine to medium clayey sand, minor coarse angular granite gneiss 16 Very hard drilling, clayey sand and cores of fresh, micaceous granite gneiss	13.00 268.75
Granitic Bedrock	16.50

Casing Above Ground Level: 0.57, medium 0.32

Casing Total Length: 16.79, medium 6.4

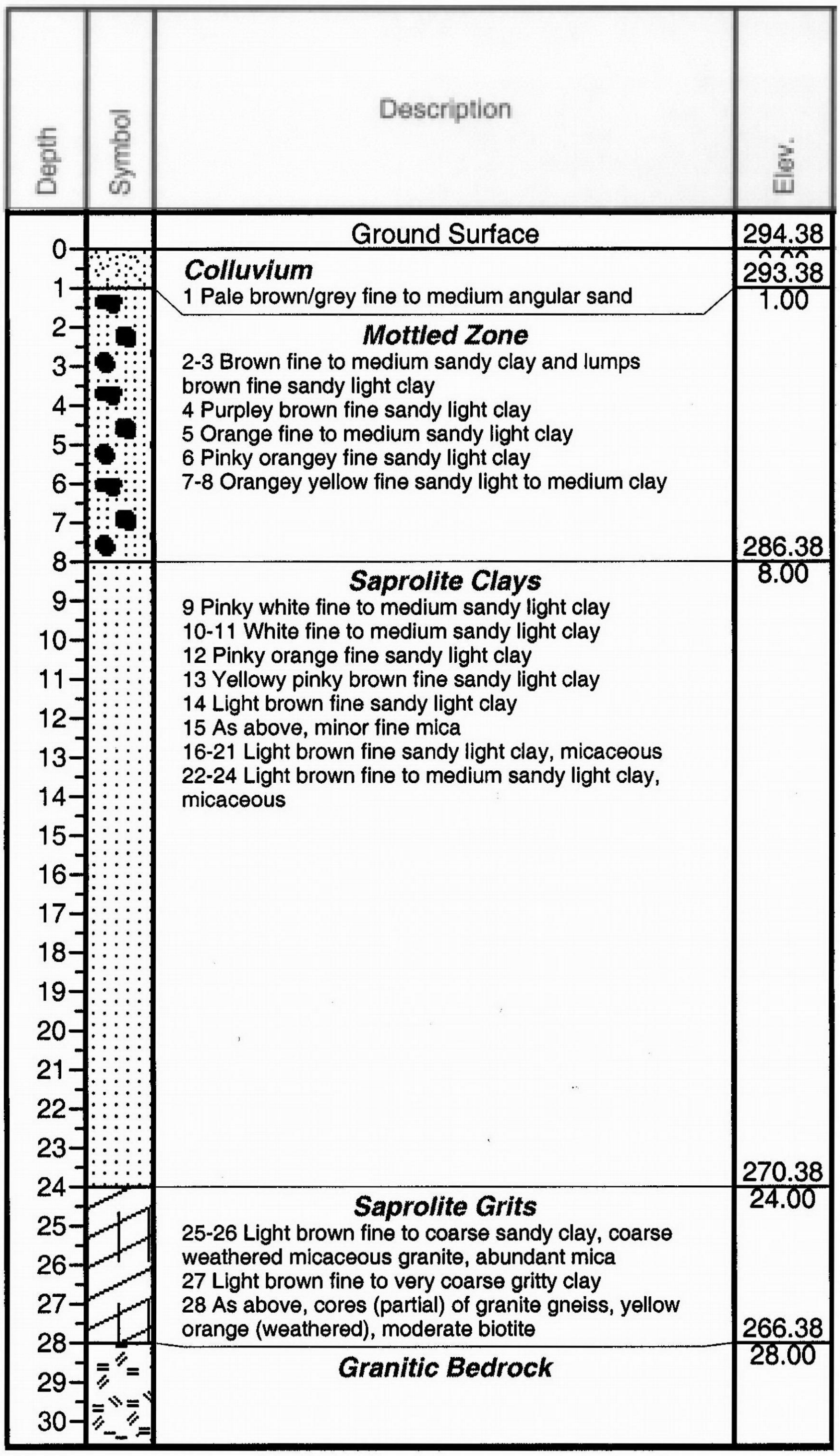
Screen: 2.0

Borehole: 00BY06D

Project:

Date: **Easting/Northing:** 540474.2 / 6286276.8

Location: **Hydrologist/ Supervisor:**



Ground Surface 294.38

0.00

Colluvium

293.38
1.00

1 Pale brown/grey fine to medium angular sand

Mottled Zone

2-3 Brown fine to medium sandy clay and lumps brown fine sandy light clay
4 Purpley brown fine sandy light clay
5 Orange fine to medium sandy light clay
6 Pinky orangey fine sandy light clay
7-8 Orangey yellow fine sandy light to medium clay

286.38
8.00

Saprolite Clays

9 Pinky white fine to medium sandy light clay
10-11 White fine to medium sandy light clay
12 Pinky orange fine sandy light clay
13 Yellowy pinky brown fine sandy light clay
14 Light brown fine sandy light clay
15 As above, minor fine mica
16-21 Light brown fine sandy light clay, micaceous
22-24 Light brown fine to medium sandy light clay, micaceous

270.38
24.00

Saprolite Grits

25-26 Light brown fine to coarse sandy clay, coarse weathered micaceous granite, abundant mica
27 Light brown fine to very coarse gritty clay
28 As above, cores (partial) of granite gneiss, yellow orange (weathered), moderate biotite

266.38
28.00

Granitic Bedrock

Casing Above Ground Level: 0.3, Intermediate 0.57
Casing Total Length: 29.5, Intermediate 12.23
Screen: 2.0

Borehole: 00BY07D

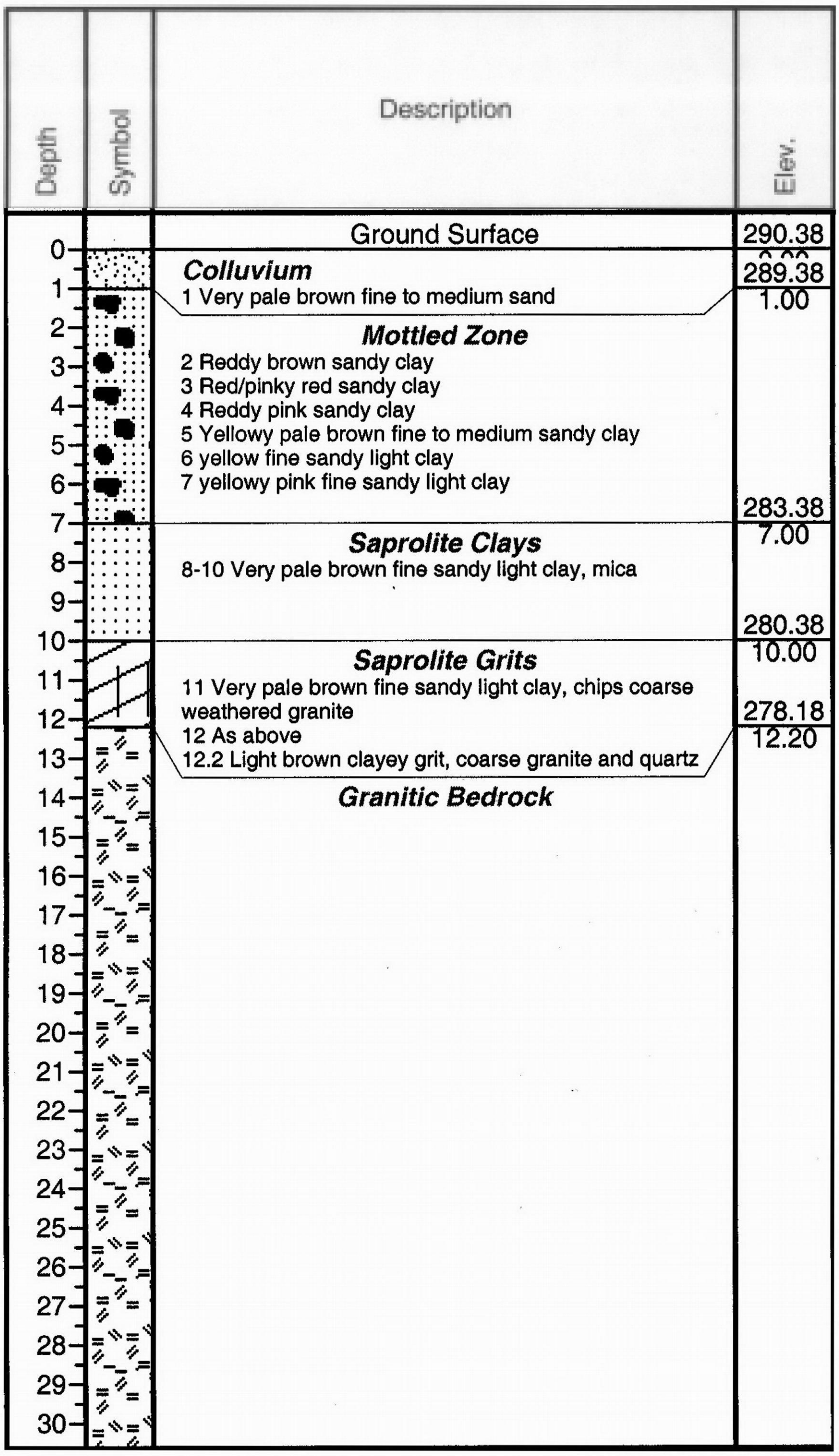
Project:

Date:

Location:

Easting/Northing: 540255.56 / 6286332.34

Hydrologist/ Supervisor:



Ground Surface

290.38

289.38
1.00

Colluvium

1 Very pale brown fine to medium sand

Mottled Zone

2 Reddy brown sandy clay
3 Red/pinky red sandy clay
4 Reddy pink sandy clay
5 Yellowy pale brown fine to medium sandy clay
6 yellow fine sandy light clay
7 yellowy pink fine sandy light clay

283.38
7.00

Saprolite Clays

8-10 Very pale brown fine sandy light clay, mica

280.38
10.00

Saprolite Grits

11 Very pale brown fine sandy light clay, chips coarse weathered granite
12 As above
12.2 Light brown clayey grit, coarse granite and quartz

278.18
12.20

Granitic Bedrock

Casing Above Ground Level: 0.5

Casing Total Length: 12.32

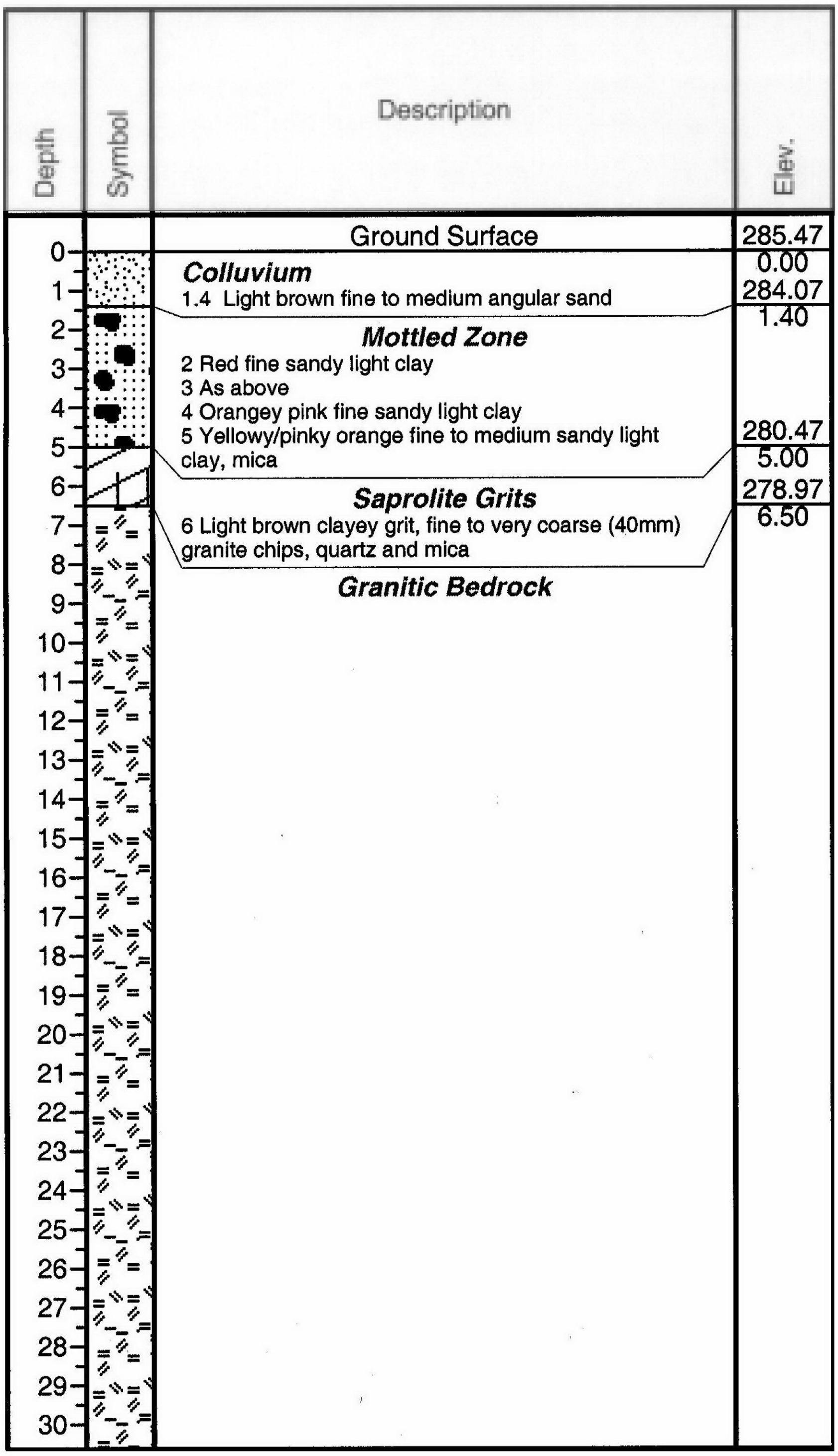
Screen: 2.0

Borehole: 00BY08D

Project:

Date: **Easting/Northing:** 540087.34 / 6286401.83

Location: **Hydrologist/ Supervisor:**



Description	Elev.
Ground Surface	285.47 0.00
Colluvium 1.4 Light brown fine to medium angular sand	284.07 1.40
Mottled Zone 2 Red fine sandy light clay 3 As above 4 Orangey pink fine sandy light clay 5 Yellowy/pinky orange fine to medium sandy light clay, mica	280.47 5.00
Saprolite Grits 6 Light brown clayey grit, fine to very coarse (40mm) granite chips, quartz and mica	278.97 6.50
Granitic Bedrock	

Casing Above Ground Level: 0.78, Shallow 0.5

Casing Total Length: 6.34, Shallow 3.14

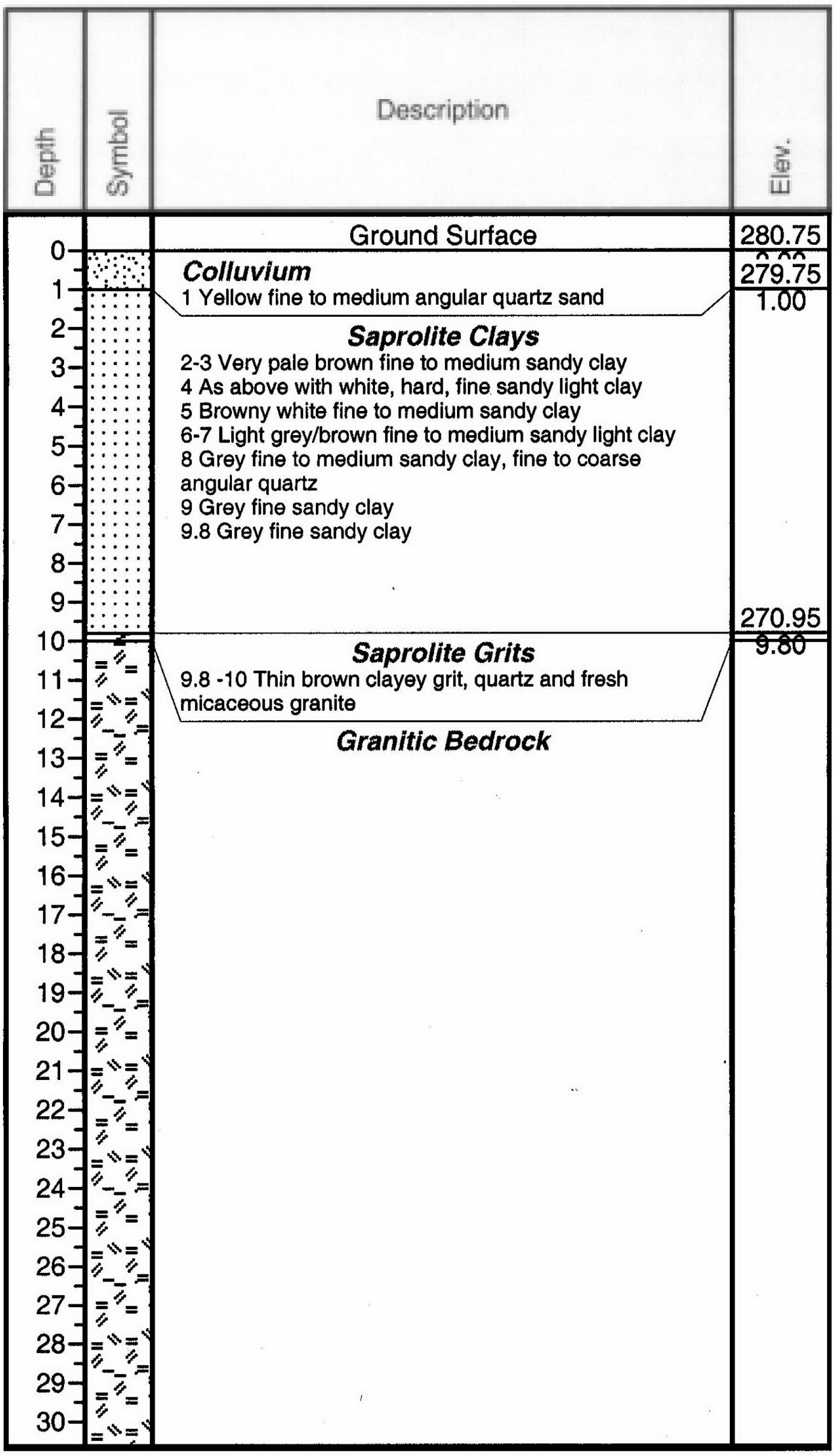
Screen: 2.0

Borehole: 00BY09D

Project:

Date: **Easting/Northing:** 539918.43 / 6286569.56

Location: **Hydrologist/ Supervisor:**



Ground Surface

Colluvium

1 Yellow fine to medium angular quartz sand

Saprolite Clays

2-3 Very pale brown fine to medium sandy clay
4 As above with white, hard, fine sandy light clay
5 Browny white fine to medium sandy clay
6-7 Light grey/brown fine to medium sandy light clay
8 Grey fine to medium sandy clay, fine to coarse angular quartz
9 Grey fine sandy clay
9.8 Grey fine sandy clay

Saprolite Grits

9.8 -10 Thin brown clayey grit, quartz and fresh micaceous granite

Granitic Bedrock

Casing Above Ground Level: 0.08, Medium .51

Casing Total Length: 9.9, Medium 6.16

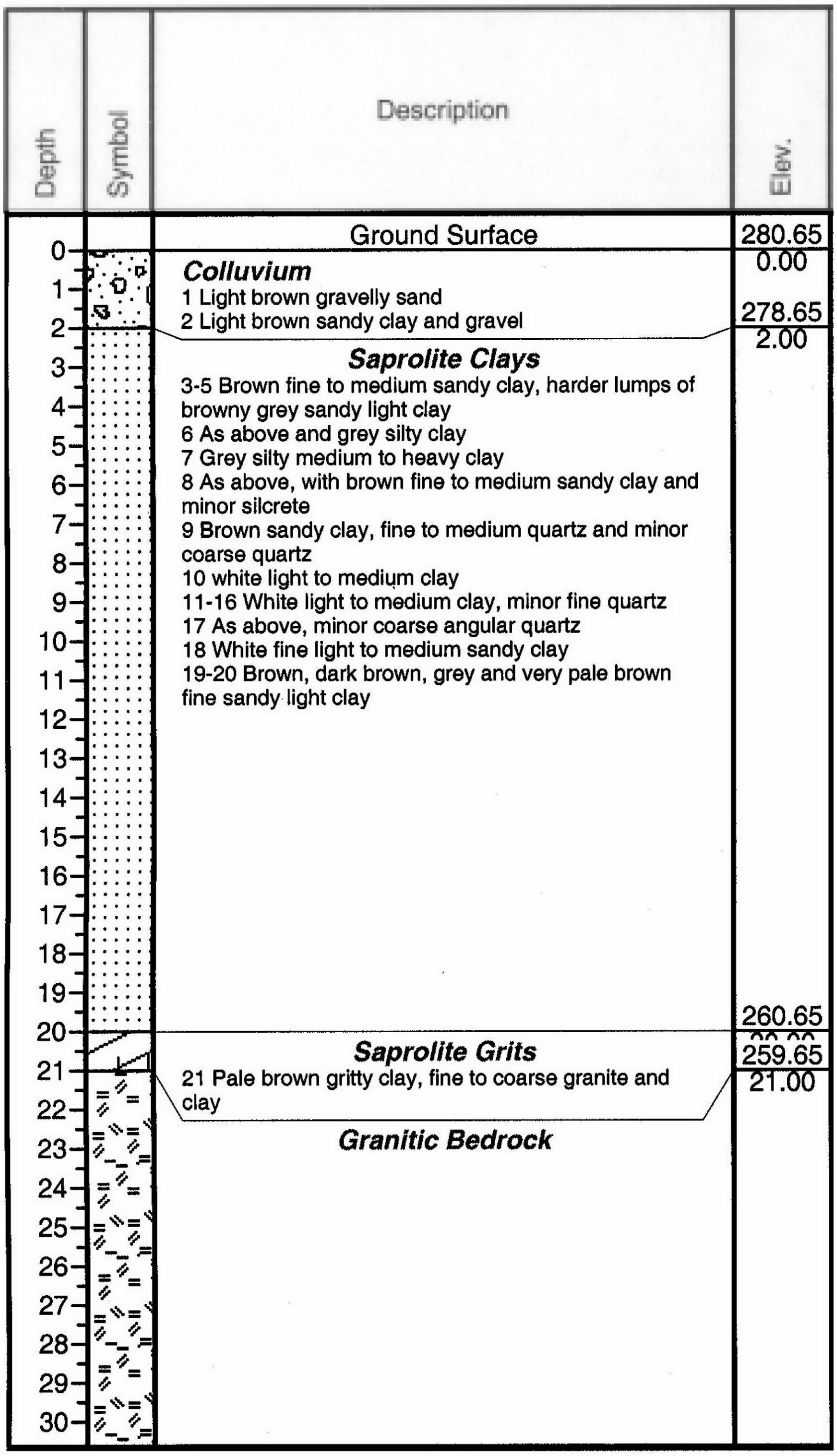
Screen: 2.0

Borehole: 00BY10D

Project:

Date: **Easting/Northing:** 539896.34 / 6286233.74

Location: **Hydrologist/ Supervisor:**



Ground Surface

Colluvium

1 Light brown gravelly sand
2 Light brown sandy clay and gravel

Saprolite Clays

3-5 Brown fine to medium sandy clay, harder lumps of browny grey sandy light clay
6 As above and grey silty clay
7 Grey silty medium to heavy clay
8 As above, with brown fine to medium sandy clay and minor silcrete
9 Brown sandy clay, fine to medium quartz and minor coarse quartz
10 white light to medium clay
11-16 White light to medium clay, minor fine quartz
17 As above, minor coarse angular quartz
18 White fine light to medium sandy clay
19-20 Brown, dark brown, grey and very pale brown fine sandy light clay

Saprolite Grits

21 Pale brown gritty clay, fine to coarse granite and clay

Granitic Bedrock

Casing Above Ground Level: 0.23, Medium 0.38

Casing Total Length: 20.68, Medium 5.89

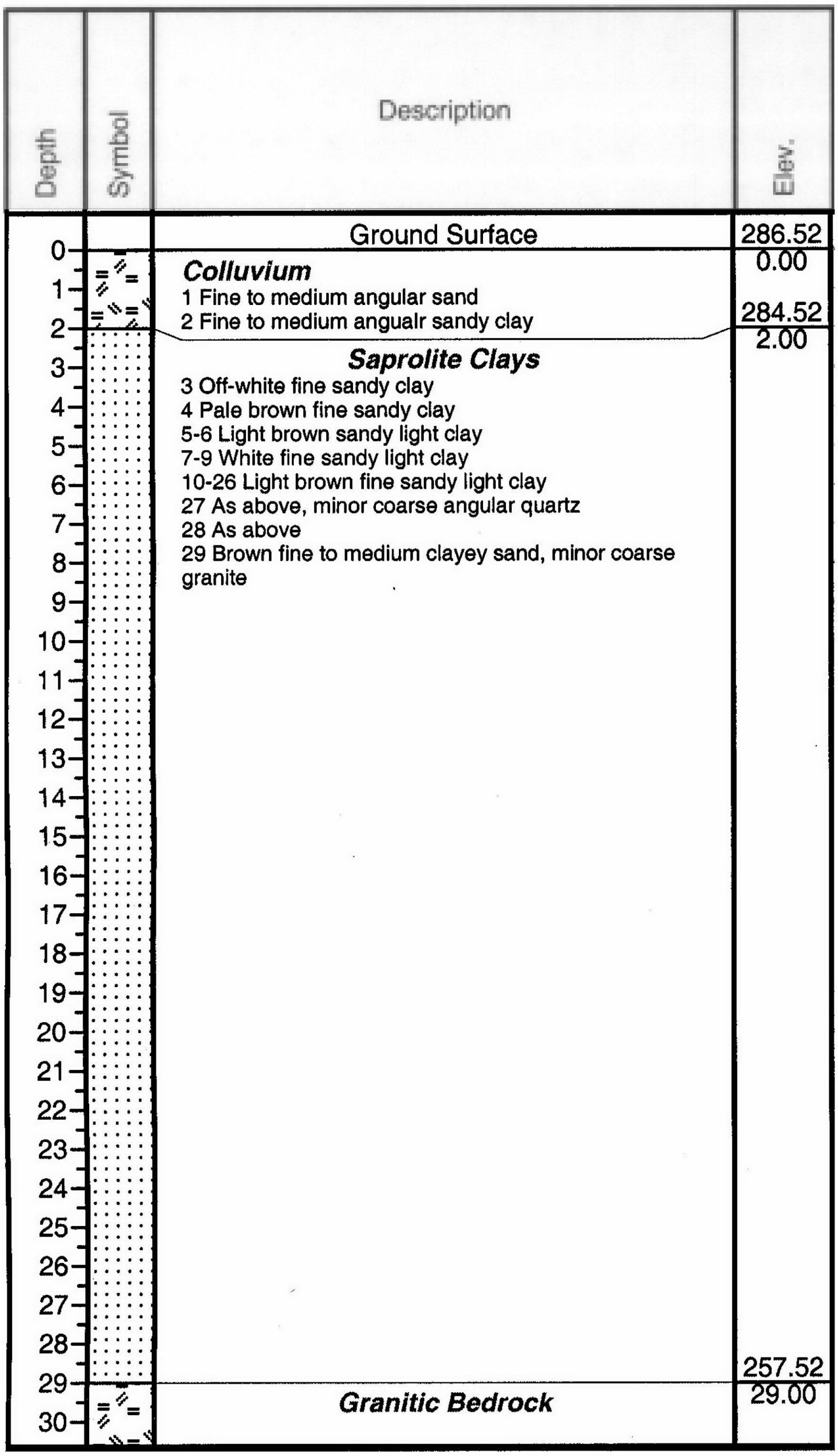
Screen: 2.0

Borehole: 00BY11D

Project:

Date: ***Easting/Northing:*** 540226.59 / 6286114.57

Location: ***Hydrologist/ Supervisor:***



Ground Surface

Colluvium

1 Fine to medium angular sand
2 Fine to medium angualr sandy clay

Saprolite Clays

3 Off-white fine sandy clay
4 Pale brown fine sandy clay
5-6 Light brown sandy light clay
7-9 White fine sandy light clay
10-26 Light brown fine sandy light clay
27 As above, minor coarse angular quartz
28 As above
29 Brown fine to medium clayey sand, minor coarse granite

Granitic Bedrock

Casing Above Ground Level: 0.38, Intermediate 0.65

Casing Total Length: 27.72, Intermediate 11.88

Screen: 2.0