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Department of Conservation and Land Management

Preliminary Hydrogeological Investigation
Northern Perth Springs
Muchea, Bullsbrook and Egerton, Western Australia

FINAL

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TABLE OF CONTENTS

1. INTRODUCTION

The Department of Conservation and Land Management (CALM) has a special interest in three springs or spring complexes on the Swan Coastal Plain, north of Perth (*Figure 1, Appendix A*). These are located at Muchea, Bullsbrook and Egerton, and a locality map for each is shown in (*Figures 2, 3 and 4, Appendix A).*

Springs on the northern Perth Swan Coastal Plain have been found to host an ecosystem comprising diverse invertebrates (Jasinska and Knott, 1984). Jasinska and Knott identified and studied other springs, however only the three springs identified above were inspected in this project as they are the only ones known in reasonable condition.

CALM and Environment Australia purchased the properties on which the Muchea and Bullsbrook springs occur. The Egerton spring is on privately owned land.

An Interim Recovery Plan (English, 1999) has been developed for the springs, and it identifies, among other recovery objectives, the need to:

- Monitor water levels and quality;
- Manage water quality and quantity; and
- Design and conduct research.

Proper management of the springs and the surrounding or adjacent land requires a better understanding of the hydrogeology of the springs.

This project represents the first component of research into the hydrogeology of the springs, and will result in progress towards achieving the Interim Recovery Plan objectives.

1.1 MOUND SPRINGS

The springs have been referred to as "tumulus" or "organic mound" springs, due to the common mounded appearance of the vegetation which grows around the spring vents and waterlogged areas. A discussion on mound springs is therefore appropriate.

1.1.1 Great Artesian Basin Mound Springs

Mound springs occur in areas of the Great Artesian Basin, especially in South Australia, where artesian water (which has a pressure sufficient to drive the water above the ground surface) discharges along geological fault lines. *Figure 5 (Appendix A)* shows a schematic hydrogeological cross-section through a mound spring in the Great Artesian Basin. Although the hydrogeology of the Great Artesian Basin is significantly different from the hydrogeology of the Swan Coastal Plain, the movement of pressurised water through a preferred pathway to the surface may be common to both areas.

The discharge of water at a spring creates a damp environment, which, depending on water quality, can support plant and animal populations. Airborne sediment and plant material combine with mineral deposits (depending on water quality) to form elevated mounds at the location of the spring.

The Great Artesian Basin hosts an extremely large aquifer system that is confined by low permeability beds above and below the major aquifers. The groundwater flow system terminates in the south and west of the basin (mostly in South Australia) where mound springs occur. These springs were thought to be in hydraulic equilibrium (flows are relatively steady over long time periods) prior to human disturbance to the supporting aquifers. The abstraction of groundwater for stock, irrigation and mining use has lowered the pressure in the aquifer, and spring flows have declined as a result.

1.1.2 Northern Perth Region Springs

Springs in the northern Perth region discharge fresh groundwater and deposition of chemical precipitates and sand is rare, but does occur to a limited extent at a few locations (Jasinska and Knott, 1984). The mounds which form at the springs represent the accumulation of peat and other vegetative matter from the lush plant growth. Rare biological communities have been observed in the springs.

It is noted that the springs that were investigated in this project have been referred to as tumulus, or mound, springs. The springs are, however, not always associated with distinct mounds. The localised groundwater discharge features that are the subject of this study will be referred to here-in as "springs", even though it is recognized that their form may vary from distributed seepage areas to mound springs with well defined vents. The term "spring(s)", as used here-in, is intended to equally represent either a single spring vent, or a complex area of groundwater discharge.

1.2 PREVIOUS INVESTIGATIONS

Mound Springs in the GAB have been investigated, and management plans for the aquifers that feed them have been developed. The primary concern in the GAB mound springs is overuse of the groundwater in the aquifer that feeds the springs, which has reduced or stopped the flows in the springs (Keane, 1997).

The location of the mound springs in the GAB was found to be controlled by two major geological factors, including:

- Erosion/outcropping of confining strata; and
- Faulting of confining strata.

There have been no known formal investigations of the hydrogeology of the springs on the Swan Coastal Plain.

Hill *et al*, 1986, mapped wetlands on the Swan Coastal Plain and categorised them in relation to their ecological importance. *Table 1.1* shows some details of the wetlands that contain the springs as they were mapped by Hill.

Table 1.1. WETLAND CATEGORISATION

Location	Identifier	Wetland Type	Preliminary Wetland Conservation Category	Wetland Map Sheet	Total Area (hectares)
Bullsbrook	208	Palusplain	Multiple Use	2034 I SE	19.5
Muchea	51Sr	Sumpland	Resource Enhancement	2034 I NE	6.1
Egerton	103Sc	Sumpland	Conservation	2034 II NE	38.4

Angus Davidson (retired) of the Water & Rivers Commission inspected the springs in the late 1990's. Davidson indicated that the springs were caused by the Guildford Clay impeding eastwards groundwater flow within the superficial formations aquifer; and that the locations of the springs were defined by local lithological variations.

1.3 SETTING

The springs lie in areas of variable but increasing development pressure.

The Muchea springs occur within Faull Street Nature Reserve near low density rural-residential housing, and although there appears to be little immediate development pressure, it is likely that rural land near the springs will be subdivided for residential use in the future. Adjacent properties, developed for rural-residential and agricultural activities, also contain springs which have been impacted by landuse including clearing, grazing and filling.

At Bullsbrook, the springs lie within Neaves Nature Reserve, and surrounding land uses are rural. The land is earmarked as a growth corridor and although development in the near future is unlikely, landuse intensity is expected to increase in the longer term. Joondalup Drive will be extended to link with Neaves Road, which forms the southern boundary of the Reserve, and traffic is likely to increase over time, although the road category is not planned to be upgraded.

Residential development is proposed for the area near the Egerton springs, however it is understood that a remnant vegetation buffer is likely to be retained.

2. SCOPE OF WORK

The following works were completed in the project.

- Obtain and review local hydrogeological data (from bore records and published/unpublished hydrogeological maps and records);
- Review published and unpublished investigations of springs in other areas of Australia and overseas;
- Conduct initial site inspection and familiarisation for all three springs;
- Develop a conceptual model of the hydrogeology of the springs, identifying the major data gaps;
- Design further investigations (initially for the Bullsbroook springs) with the objectives of:
  - completing the data gaps by further research, on-site investigation and groundwater modeling as required;
  - providing a link between the investigation work conducted at Bullsbrook and the likely implications of the findings on the other sites; and
  - developing management measures to protect the springs.
- Prepare and submit a bound report providing:
  - data summaries
  - hydrogeological cross-sections and maps as required
  - discussion of the work undertaken and presentation of the likely mechanisms that support the mound spring
  - recommendations and designs for further investigations.

This desktop and field investigation was scoped to:

- develop a preliminary understanding of the likely hydrogeology of the springs; and
- design an appropriate investigation and monitoring bore network.

This project was initially to be focused on the Bullsbrook springs. As the project progressed, it became apparent that the simultaneous evaluation of all three sites was more appropriate than a more detailed evaluation of a single site. There are elements common to the sites that provide a more rigorous understanding of the hydrogeological processes at work.

3. GEOMORPHOLOGY, DRAINAGE AND SOILS

All three springs lie in the eastern portion of the Swan Coastal Plain, in the upper reaches of the Ellen Brook catchment. Surface water usually does not occur (except within the springs), however in late winter, high water tables result in temporary waterlogged and flooded areas, and some shallow drains allow movement of water towards Ellen Brook from the springs.

The land surface at all three sites comprises either elevated undulating land (Bullsbrook) to the west, or elevated sandy dune ridges (Muchea and Egerton) to the west. Each of the springs occurs at a relatively low elevation on the eastern flank of a dune or break of slope.

Soils to the west of the springs are well-drained pale grey quartz sand (Bassendean Sand) and clayey soils (Guildford Formation) occur to the east of each of the springs. The Guildford Clay is commonly overlain by a veneer of residual Bassendean Sand, up to a metre or so thick.

4. HYDROGEOLOGY

The discussion of the hydrogeological environment of the springs is restricted to the near-surface (about the upper 50m) superficial formations aquifer, as it is not considered that the major confined aquifers (such as the Leederville Formation) have a significant local impact on the springs. Confined and artesian groundwater conditions can occur on a local scale within the normally unconfined superficial formations, and these conditions should not be considered to be a reference to the deeper aquifers. A brief discussion of a possible role of the Leederville aquifer is provided later.

4.1 SHALLOW AQUIFERS

The Swan Coastal Plain overlies a series of aquifers, the shallowest of which is termed the superficial formations. The superficial formations is around 30-50m thick in the region of interest, and consists mainly of sand, silt, clay and limestone in varying proportions (Davidson, 1995). The Bassendean Sand (quartz sand with minor clay layers) and the Guildford Formation (mostly clay and silt, with a basal sand unit and sandy lenses) are the dominant units in the superficial formations near the sites.

Davidson (1995) maps the Bassendean Sand, which occurs to the west of, and interfingers with, the Guildford Clay (*Figure 6, Appendix A*). The boundary between the units occurs at the locations of the springs in each case. Environmental Geology mapping (Muchea 1:50,000) shows near-surface soils on a more local scale, and confirms that the springs lie on the boundary between the Bassendean Sand and the Guildford Clay.

Figure 7 (*Appendix A*) includes hydrogeological cross-sections of the superficial formations in the area near the springs. Local bore data were reviewed, and although the general pattern shown in *Figure 7* is evident, the data are not sufficient to determine detailed lithological variations at a local scale.

4.2 GROUNDWATER LEVELS AND FLOWS

The Gnangara Mound, which lies to the west of the springs, represents a region of elevated, or mounded, groundwater levels, where the groundwater salinity is low. Both of these qualities are due to enhanced rainfall recharge. The groundwater in the mound flows radially outwards towards the Indian Ocean (west) and the Swan River (south), Ellen Brook (east) and Gingin Brook (north).

Regional groundwater flow directions are shown by water table elevation contours (*Figure 8, Appendix A*), from Davidson (1995). Groundwater generally flows from areas of high groundwater elevation to areas of low groundwater elevation, at right angles to the contours. Local flow directions in the shallow aquifer are likely to be slightly different from those indicated on the regional map, due to variations in landuse (and thus rainfall recharge) groundwater use and aquifer properties. However, the overall easterly to south-easterly direction of groundwater flow is expected to be representative.

Local flow directions in the aquifer are likely to be affected by groundwater discharge at each spring, and thus site-specific investigation is required to define capture zones.

Davidson (pers. comm., 2002) indicates that a large component of the easterly flowing groundwater within the superficial formations discharges to Ellen Brook, with a smaller component being diverted to the south and possibly into underlying aquifers.

4.3 INTERACTION BETWEEN GROUNDWATER AND WETLANDS

The interaction between groundwater and wetlands on the Swan Coastal Plain has been extensively investigated. Townley *et al*, 1993 described the interactions in detail. In summary, groundwater flows through the unconfined aquifer, and preferentially flows in zones with higher transmissivity (ie those that are more permeable or where the aquifer is thicker). Where the water table lies above the ground surface, such as in a wetland or lake, the low resistance to flow through the surface water body "captures" groundwater flow, in a similar way to heat or electricity passing preferentially through a good conductor. Thus groundwater can enter a wetland by horizontal flow, and can also be diverted upwards from a significant depth within the aquifer.

4.3.1 Wetland Types

Wetlands can be categorized as groundwater discharge, groundwater recharge, or groundwater throughflow wetlands. Most of the wetlands on the Swan Coastal Plain receive groundwater discharge at the upgradient side, and contribute to groundwater recharge on their downgradient side (as described above) and these are termed "groundwater throughflow" wetlands. Groundwater recharge wetlands (which receive a large component of surface water input and discharge it to groundwater) or groundwater discharge wetlands (which are fed by groundwater which is removed as surface runoff or evaporation) also occur, but are rarer.

Simplistic cross-sections of these wetland types are presented as *Figure 9 (Appendix A).*

The springs are thought to represent a variant of groundwater discharge wetlands, where groundwater discharges at the spring, forming a localised surface water body. The surface water is then removed as runoff or evaporation, or recharges the shallow aquifer near the spring (where the groundwater level is lower than the groundwater level in the aquifer which is discharging at the spring).

In either case, the springs effectively receive groundwater from an as-yet undefined portion of the superficial formations aquifer.

4.3.2 Wetland Capture Zones

The groundwater capture zone for a wetland can be defined both vertically and laterally, by considering groundwater pressures, in a similar fashion as consideration of ground elevations to determine surface water catchments. However, as detailed groundwater pressure maps can only be generated by installation of a number of bores, accurate capture zones cannot usually be defined, and estimates must be used.

Townley *et al* 1993 found that the vertical capture zone of a groundwater throughflow wetland, which intersects an unconfined aquifer, extends to the full thickness of the aquifer when the length of the wetland is five to ten times the thickness of the aquifer. The length of the wetland is measured in the direction of groundwater flow. This rule of thumb assumes that the aquifer is uniformly sandy, however the springs that are the subject of this study occur near a thick clayey section of the aquifer and therefore their groundwater capture zone is more complex.

The horizontal capture zone is more easily measured for large wetlands where there are regional monitoring bores, enabling horizontal groundwater flow directions to be mapped. Wetland capture zones are typically two to three times as wide as the wetland (width is measured perpendicular to the groundwater flow direction).

As the mechanism that drives the mound springs is not currently known, the capture zone, and therefore the extent of the aquifer or land area which should be managed, is not known. Further investigations are required to enable the capture zone for the springs to be defined.

It is likely that the changes in aquifer lithology at the springs makes it difficult to assess the springs with reference to typical groundwater-surface water interactions, and on-site data are required.

4.3.3 Groundwater Vulnerability

The vulnerability of groundwater to contamination was mapped by Appleyard (1993) (*Figure 10, Appendix A*). Appleyard ranked groundwater vulnerability to landuse impact by considering the depth to groundwater and the soil type. Sandy soils and shallow depths to water resulted in a higher degree of vulnerability being assigned. Appleyard ranks the areas of the springs a "Very High Vulnerability", and this ranking applies to the very shallow water tables near the wetlands. The catchment areas (west of the springs) are ranked "High Vulnerability", as they have a greater depth to groundwater.

4.4 LOCAL GROUNDWATER USE

The distribution and abstraction limit for groundwater well licences issued for the superficial formations near each of the sites are shown in *Figures 11, 12 and 13 (Appendix A).*

The authorized annual abstraction limits for each licence holder are annotated in the Figures referenced above. The abstraction limits represent the maximum that may be pumped. However, it is likely that there is significant variation between the licensed allocation and the actual volume of groundwater that is being drawn. The pattern of use (whether strongly seasonal or otherwise) is also likely to vary. There may also be some groundwater use outside the Water & Rivers Commission's allocation database, most likely for stock and domestic use (which is probably insignificant).

Further review of the extent of actual groundwater use and the portion of the aquifer from which groundwater is being drawn (in relation to the portion of the aquifer which supports the springs) is required. Intuitively, larger groundwater users at close distances from the springs give the greatest concern. Once actual use has been established, the potential impact of pumping on groundwater levels near the springs can be assessed.

5. SITE INSPECTION

The mounds springs at Muchea, Bullsbrook and Egerton were inspected in late August and early September, 2002.

Some characteristics of the springs were observed and are recorded below. It is likely that more detailed inspection and mapping of the springs would add to the understanding of their local distribution. However, as the purpose of this project is to work towards development of catchment management measures, detailed mapping has been left for a later stage.

The reader is referred to Jasinska and Knott (1984) for detailed descriptions and photographs of the springs at Muchea and Egerton. The Bullsbrook springs were not studied in their investigation.

5.1 MUCHEA

The springs occur on the eastern footslopes of a dune ridge comprising Bassendean Sand, oriented NNW-SSE. Land to the east is flatlying, and comprises thin Bassendean Sand overlying Guildford Clay.

The springs lie at the eastern end of a block comprising mostly native vegetation. Inspection of the surrounding areas shows springs and seeps occurring along the footslope of the sand dune. A well defined spring was noted by Jasinska and Knott to the north of this property.

The springs appear to comprise an irregular, discontinuous seepage face, and there was no discernible flow at the time of the site inspection. Standing water, observed in an area of dense vegetation, was presumably supported by groundwater discharge.

5.2 BULLSBROOK

The springs occur at the foot of a small (3-5m) scarp which is caused by erosion of the Bassendean Sand. The lowlying area drains northwards, then eastwards, and becomes a tributary to Ellen Brook.

Superficial examination of the area shows a number of variably well defined vegetated "mounds" (comprising decaying vegetation) with water discharging from them. A detailed inspection indicated that there is a significant discharge of water (over 1L/s) from the foot of a sand scarp which occurs about 10m west of the vegetated mounds.

It was not possible to determine whether the water discharging from the visible spring flows (as noted above) through the decaying vegetation and appears to represent a number of isolated springs, or whether the area hosts a complex of springs with different sources.

5.3 EGERTON

The Egerton springs occur on an incised, forked drainage line that has cut into a sand dune to the west by headward erosion. The drainage line is up to 2m deep and exposes sandy banks throughout. Observation of local elevations indicate that the floor of the drainage line is several metres or less above the Guildford Clay which forms the subsoil beneath the cleared paddocks to the east.

The point of discharge was not visible due to the dense vegetation, and may comprise either steady increases in flow along the length of the drainage line, or individual contributions from localised springs. Jasinska and Knott (1984) describe a localised mound spring but this was not located. In either case, the discharge area is limited to the upper 100 to 200m of the drainage line, where lush vegetation was observed. Further downstream the drainage line flanks relatively dry bush although the flow does not substantially reduce with distance from the source. These observations indicate a localised area of groundwater discharge.

5.4 COMMON ELEMENTS

Each of the springs comprises the following common elements:

- Sandy elevated land to the west;
- Clayey soils to the east and at shallow depth;
- Relatively localised discharge of groundwater;
- Possible evidence of both confined and unconfined groundwater discharge; and
- Year-round discharge of groundwater.

The next Chapter reviews the spatial relationships between the hydrogeological features of the superficial formations aquifer and the locations of the springs.

6. SPATIAL RELATIONSHIPS

The locations of the spring shave been plotted on a series of maps showing particular elements of the hydrogeology of the superficial formations.

The spatial datasets thus plotted include:

- Surface geology;
- Aquifer saturated thickness;
- Groundwater elevation and flows; and
- Transmissivity (and chloride concentrations).

6.1 SURFACE GEOLOGY

Figure 6 (Appendix A) shows each of the springs plotted onto surface geology. The springs each occur near the boundary between the Bassendean Sand and the Guildford Clay.

6.2 AQUIFER SATURATED THICKNESS

The aquifer saturated thickness represents the thickness of the aquifer between the base of the aquifer and the water table.

The saturated thickness at each of the springs varies (*Figure 14, Appendix A*), however at each spring, the thickness is decreasing with distance to the east. The area of the springs coincides with the steepest rates of change of the aquifer thickness in the Perth region.

The occurrence of the Guildford Clay to the east of the springs further reduces the effective saturated thickness of the superficial formations aquifer, as the low permeability materials do not effectively transmit water.

6.3 GROUNDWATER ELEVATIONS AND FLOWS

Groundwater flows radially from the Gnangara Mound, and the springs lie on the south-eastern flank of the Mound. Groundwater flow directions at and near Ellen Brook are southerly, in the direction of surface drainage.

Groundwater is flowing to the east and south at each of the springs (*Figure 8, Appendix A*), from the Bassendean Sand, and through the Bassendean Sand and underlying Gnangara Sand, under the Guildford Clay, towards Ellen Brook.

The groundwater flownet was generated based on contoured groundwater table elevations for the superficial formations. The directions of groundwater flow are marked.

6.4 TRANSMISSIVITY

Aquifer transmissivity represents the total capacity of the aquifer to transmit water, by natural flow or to a bore. The transmissivity is the product of the permeability and the thickness of the aquifer.

The transmissivity of the aquifer is different at each spring (*Figure 15, Appendix A*), but again it is reducing with distance to the east (along the groundwater flow path) at each spring. This reduction is due to both thinning of the aquifer, and the increasing component of low permeability materials.

6.5 CHLORIDE CONCENTRATIONS

The chloride concentrations of the groundwater are useful for assessing groundwater flow directions, as chloride does not react with the aquifer, and any changes are a direct result of either dilution by rainfall recharge, evaporation, or mixing with water of a different quality.

The chlorinity of the water (*Figure 16, Appendix A*) increases to the east at each spring, and supports the physical indicators of easterly groundwater flow.

6.6 SURFACE TOPOGRAPHY AND LITHOLOGY

At each spring, there is a distinct break in slope from high ground to the west to low ground in the east. The higher ground comprises relatively permeable Bassendean Sand, which overlies and abuts Guildford Clay to the east. The Bassendean Sand has been eroded from the Guildford Clay by surface drainage toward Ellen Brook.

6.7 DISCUSSION

Basic analysis of the above datasets indicates that a broadly similar mechanism probably causes the occurrence of each of the springs, however there are two reasonable mechanisms that have different implications for land management.

6.7.1 Hydraulic Mechanism

In a regional sense, the aquifer to the west of the springs comprises relatively high permeability sand, with a significant saturated thickness. The transmissivity (or capacity of the aquifer to transmit water) is high. The groundwater flow direction on the eastern flank of the Gnangara Mound is to the south and east. As the groundwater flows to the east, the aquifer becomes more fine-grained (less permeable) and thinner, and the transmissivity is reduced. The hydraulic gradient steepens as the water pressure required to drive water through the aquifer with a lower transmissivity is increased. Springs may occur where the groundwater pressure is above the ground surface.

Consider the case where the water pressure is above the surface. The nature of groundwater discharge will be different depending on whether the aquifer is confined (overlain by clay or low permeability material) or unconfined (the aquifer comprises only sand). Remember the Guildford Clay occurs at and to the east of the springs. It is possible that unconfined and confined conditions occur, either vertically or horizontally separated, in different parts of the same aquifer.

6.7.2 Unconfined Aquifer

An unconfined aquifer with a high water level will "seep" groundwater in a zone bounded by the elevation of the water pressure, and which will extend throughout the area where the groundwater pressure is above the ground surface. This is often observed as a continuous seepage face on the upgradient shoreline of a groundwater throughflow wetland (similar to seepage on a beach at low tide).

If a clay layer underlying (and possibly perching) the aquifer was exposed, the combination of surface topography and the geometry of the clay layer may cause the discharge point to be localised. This mechanism may be occurring at Bullsbrook.

6.7.3 Confined Aquifer

A confined aquifer with water pressure above ground level (an artesian aquifer) would cause springs to flow if there are conduits or permeable zones in the confining bed. The springs will only occur in the region of artesian pressure, and the exact location and dimensions of the springs would depend on the nature of the conduit or permeable zone through which the groundwater flows.

The occurrence of localised springs at variable elevations (with an upper limit controlled by the groundwater pressure) is indicative of a confined artesian aquifer. The locations of the springs will be controlled by relatively permeable zones in the confining layers, such as tree-root holes, excavations, or areas of thin/absent Guildford Clay.

Note that artesian groundwater conditions simply indicate that the groundwater pressure is above the ground surface, there is no requirement for the aquifer to contain large quantities of fresh groundwater, as is commonly understood.

6.7.4 Leederville Formation

The Leederville Formation is a major aquifer that is developed for public and private groundwater supply. Groundwater pressure in Leederville aquifer is unlikely to have any impact on the springs on a local scale as there is between 120 and 180m of low permeability units (Osborne Formation and Coolyena Group, which contain minor local aquifers), between the Leederville Formation and the superficial formations.

The Leederville Formation is overlain directly by the superficial formations approximately 5-10km west of the springs, beneath the Gnangara Mound. In this region, changes in groundwater pressure in the Leederville Formation may result in changes in the groundwater level within the superficial formations. Such regional changes are controlled by extensive land and groundwater management and climatic factors, and are therefore unrelated to local management of the springs.

Downwards leakage to the Mirrabooka Aquifer (which is a locally important aquifer, used for private irrigation) has been identified in the region in which all three springs lie (Davidson, 1995). This leakage may be slightly increased if the Mirrabooka Aquifer is depressurised by over-use, however the intervening low permeability strata (total thickness around 50-80m) indicate that this leakage is probably a very small component of the water balance in the region of the springs.

The management of the springs on a local scale should clearly be focussed on delineation of the mechanism that drives the springs and the capture zone within the superficial aquifer. Changes in groundwater pressures in deeper aquifers have a small potential to impact the springs, however this is on a regional scale and is outside the scope of this investigation.

6.7.5 Vegetation Accumulation

The accumulation of vegetation at the spring discharge may impede the continued discharge of groundwater, encouraging migration of the discharge area or formation of new springs at an adjacent weak point. Thus areas of spring discharge may "heal" naturally, leaving a remnant mound of vegetation.

This process may be responsible for the formation of the organic mounds.

6.7.6 Sediment/Precipitate Formation

Discharge of particulate material (silt or sand) from springs has been observed by Jasinska and Knott (1984). This is likely to occur in the early stages of development of a new spring vent, when high water velocity can erode and carry sand from the aquifer or the vent walls. As the vent is eroded, the slower entrance velocity will become insufficient to erode sediment and the discharge of sediment will cease.

The low water salinity precludes significant deposition of chemical precipitates, however Jasinska and Knott (1984) noted minor precipitation of a suspected calcium/magnesium carbonate at some springs.

6.7.7 Interpreted Mechanism

Figure 17, Appendix A shows the interpreted mechanisms behind the springs, and a text description is provided below:

- Groundwater in the superficial formations (Bassendean Sand aquifer), on the eastern flank of the Gnangara Mound, is recharged by rainfall infiltration on the mound and flows to the east.
- As the groundwater meets the interfingered western margin of the Guildford Clay, vertically distinct aquifers are formed.
- The uppermost aquifer is unconfined, and lies on a low permeability unit of the Guildford Clay.
- The uppermost aquifer discharges to the surface where the aquifer has been eroded, and the remaining thickness of the aquifer is insufficient to transmit the groundwater at the prevailing hydraulic gradient.
- Deeper parts of the aquifer are confined under the Guildford Clay, and the water pressure induced by the restriction to eastward flow is released vertically upwards through permeable zones or hydraulic weaknesses in the Guildford Clay, discharging to the surface where local conditions are favourable.

6.7.8 Data Gaps

The following data gaps (restricted to those relevant to evaluating the hydrogeology of the springs as it relates to land and water management) have been identified, and are listed in order of decreasing priority:

- to what extent the unconfined and confined mechanisms contribute to the springs, (evidence of both was observed by the author or described in previous investigations).

- The hydraulic pressures that drive the springs and changes in those pressures over time;

- The groundwater quality (with respect to landuse impacts especially) in the aquifer that drives the springs and changes in water quality over time.

- The depth at which the hydraulic pressures occur, and the significance of the pressure vs depth profile (which allows the groundwater catchment to be defined) with respect to land and water management;

- The detailed geometry of the clayey units which are thought to subdivide the aquifer, and whether this information would assist in better land and water management.

Further hydrogeological investigations into the springs should be focussed clearly on providing information to improve the knowledge of the hydrogeology of the springs, not just from a scientific or academic viewpoint, but such that more effective and efficient land and water management is possible.

7. MANAGEMENT IMPLICATIONS

The current understanding of the hydrogeological cause of the mound springs is robust, but lacks detail. Specifically, the groundwater catchment for the springs will depend on the two inferred major mechanisms for their occurrence. Localised land management may be sufficient if an unconfined aquifer supports the springs, however a more regional management approach may be required if a deeper, confined (superficial formations) system supports the springs.

Intuitively, the land to the west of the springs will be the main focus of land management to protect the groundwater quality at the springs. Management of groundwater use to control the effect of any drawdown on the springs would be also focussed to the west, however large scale use of groundwater near the springs in any direction may have potential to induce an impact. It is noted that existing licensed groundwater use is generally to the west of the springs at Muchea and Bullsbrook.

Delineation of the groundwater catchment area (both vertically and horizontally) for the springs, as well as the area in which groundwater use may impact the springs, is required to appropriately manage the land and water use. Currently, small land areas to the west of the Muchea and Bullsbrook springs are owned and managed by CALM, and they comprise native vegetation. It is understood that land to the west of the Egerton springs is proposed to be developed for urban use, although an undisturbed buffer would be maintained.

Groundwater use near the springs is managed within existing environmental and water rights legislation. There is potential for large scale groundwater use near the springs to impact on local groundwater pressures.

The major issues likely to arise in ongoing management of the springs are:

- Long term climate projections (sustained low rainfall may cause spring flows to reduce or cease);
- Local shallow groundwater use (<15m deep bores west of the springs);
- Local and regional deep groundwater use (15-50m deep bores near and west of the springs);
- Landuse compatibility in areas west of the springs; and
- Overall decline of groundwater levels in the Gnangara Mound as a result of a combination of groundwater uses and low rainfall.

8. RECOMMENDATIONS

An on-site investigation is required to:

- Evaluate the groundwater pressure distribution (vertically and horizontally) and aquifer lithology (to define local groundwater flow directions); and
- Test groundwater quality variations (focused on major hydrochemistry initially);
- Define the system or systems which maintain the spring flows (whether unconfined or confined);
- subsequently identify areas of land and portions of the aquifer in which special attention to land and groundwater use should be paid.

It is recommended that on-site investigations be conducted at either Bullsbrook or Muchea due to ease of land access, although it is recognized that the bushland vegetation at each site should be protected as far as is possible. Any proposed works would need to be planned and assessed with reference to the potential to disturb the sites.

8.1 INVESTIGATION SCOPE

The scope of work for such an investigation would comprise four steps:

- Site mapping;
- Shallow investigation;
- Deep investigation; and
- Monitoring and Data Compilation.

8.1.1 Site Mapping

- Map (with a hydrogeological focus) the springs at the selected location based on groundwater discharge features, surface water flow, water quality, water elevations, soil type, and vegetation type and vigour.

8.1.2 Shallow Investigation

- Hand augering at up to nine locations to define the lithology within the upper 2-5m;
- Installation of 50mm diameter PVC piezometers with 1m slotted intervals (or as appropriate) in the hand augered holes (this may require additional equipment depending on ground conditions); and
- Preliminary water sampling and field chemistry testing.

Note that setting of screen intervals and sealing of the borehole annulus requires particular attention to detail.

8.1.3 Deep Investigation

- Completion of gamma logs in selected existing private bores within approximately 500m of the springs to assess local lithological variations at depth;
- Review of the results of the Shallow Investigation and the gamma logging completed above, focusing on selection of locations and depth intervals of interest within the superficial aquifer; and
- Installation of up to four 100mm diameter PVC monitoring bores, screened in the intervals of interest, and at locations that allow the data gaps to be closed.

Again, setting of screen interval and sealing of the borehole annulus requires particular attention to detail.

8.1.4 Collation of Data, Conceptualisation and Monitoring

- Surveying, gauging, water sampling and chemical analyses of all bores and piezometers tested or installed in the programme;
- Construct hydrogeological cross-sections of the aquifer considering groundwater quality, groundwater pressures, aquifer lithologies and connectivity between aquifer units;
- Develop a conceptual model of the hydrogeological mechanisms that support the springs; and
- Monitor groundwater levels and salinity on a monthly basis for a minimum of twelve months, and report the data with a brief review of any implications.

Figure 18, Appendix A shows the notional locations for the shallow investigation bores specified above. The actual locations would be expected to differ as the results from each bore should be used to revise or alter the programme to reflect the aquifer conditions.

The locations of deep bores would be decided at a later stage when additional on-site information became available.

On behalf of Groundwater Consulting Services Pty Ltd,

SAM BURTON
MANAGING DIRECTOR.

9. REFERENCES

Appleyard, S. J., 1993.
"Explanatory Notes for the Groundwater Vulnerability to Contamination Maps of the Perth Basin". Geological Survey of Western Australia, Department of Minerals and Energy, Report 1993/6

Davidson, W. A., 1995.
"Hydrogeology and Groundwater Resources of the Perth Region Western Australia". Geological Society of Western Australia, Bulletin 142.

English, V., 1999.
"Assemblages of Organic Mound (Tumulus) Springs of the Swan Coastal Plain": Interim Recovery Plan, Department of Conservation and Land Management, unpublished internal document.

Hill et al 1999
"Wetlands of the Swan Coastal Plain Wetland Mapping, Classification and Evaluation. Wetland Atlas". Water and Rivers Commission, Volume 2B

Jasinska, E.J. and Knott, B., 1994
"Aquatic Fauna in Gnangara Mound Discharge Areas of the Ellen Brook Catchment, Western Australia". Department of Zoology, University of Western Australia.

Keane, D., 1997
"The sustainability of use of groundwater from the south-western edge of the Great Artesian Basin, with particular reference to the impact on the mound springs of the borefields of Western Mining Corporation". Unpublished thesis, Department of Civil and Geological Engineering. Environmental Engineering Design 4 Investigation Project.

Townley LR, Turner JV, Barr AD, Telfrey MG, Wright KD, Gailitis V, Harris CJ, Johnston CD 1993
"Wetlands of the Swan Coastal Plain Volume 3- Interaction between Lakes, Wetlands and Unconfined Aquifers". Water Authority of Western Australia, Environmental Protection Authority.

10. LIMITATIONS

Groundwater Consulting Services Pty Ltd has prepared this report for the Department of Conservation and Land Management in accordance with generally accepted consulting practice. The specific conditions of the contract and subsequent communications have had a bearing on the depth and breadth of the project and on the confidence in the findings. When client constraints, whether express or implied, have limited the scope of work, a lower than normal confidence may occur.

The confidence in the ability of a groundwater resource to support a nominated withdrawal of groundwater is subject to spatial and temporal variations in the aquifers, climate and landuse that may not be known or predictable. Conservative assumptions will have been used where-ever possible, however, estimates of bore yield or predicted impacts of pumping can be incorrect, especially where conditions on which predictions were made have been changed. Groundwater Consulting Services Pty Ltd's predictions are made on the basis that Groundwater Consulting Services Pty Ltd will be contracted to undertake regular reviews of operational data that may lead to groundwater availability or quality predictions being re-estimated.

Groundwater Consulting Services Pty Ltd does not provide advice on crop water requirements, irrigation schedules, irrigation system design and other non-groundwater related areas. Groundwater Consulting Services Pty Ltd's advice on bore placement and operation must be considered by the proponent with reference to expert advice from other disciplines.

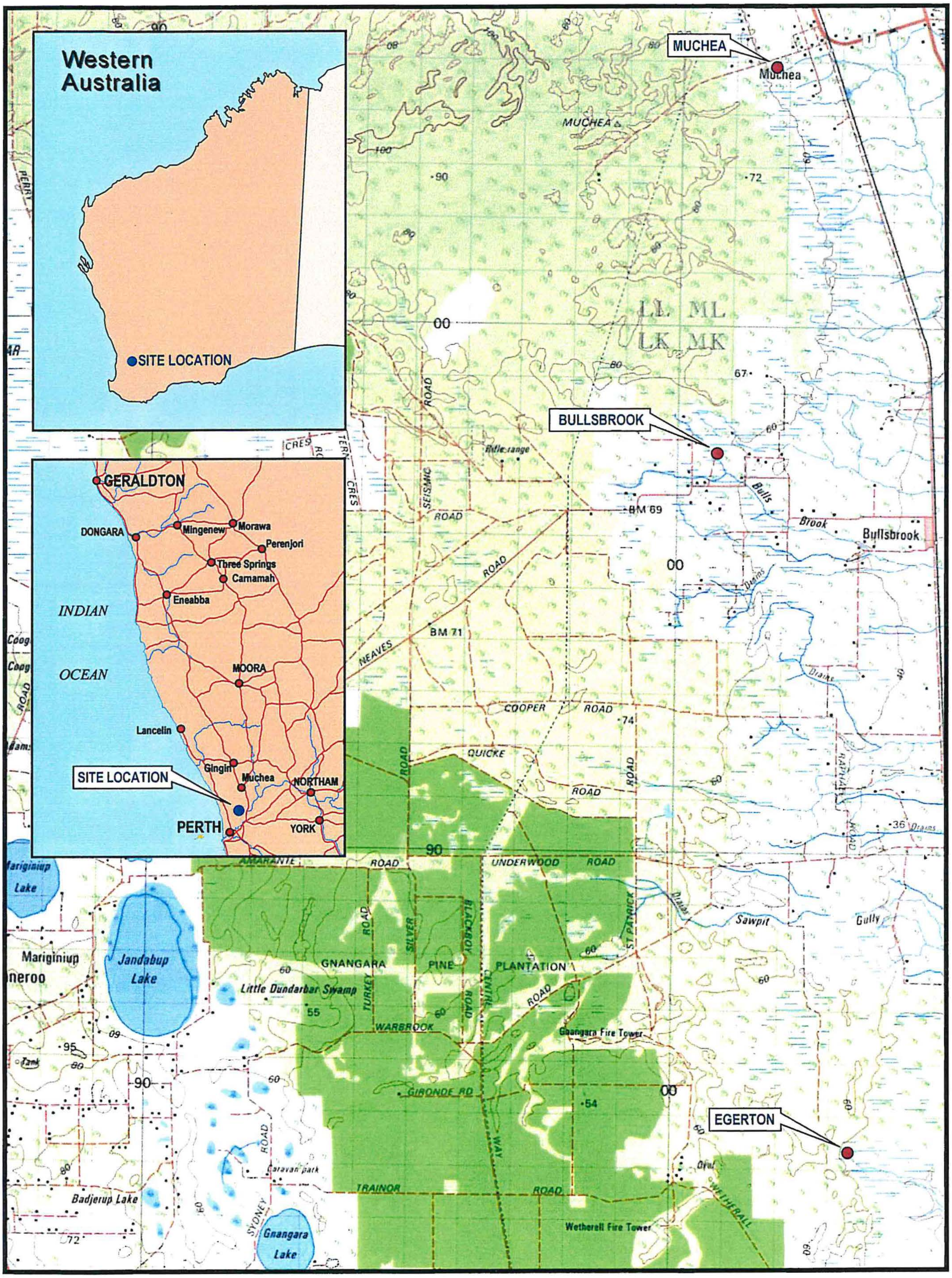
The project for which Groundwater Consulting Services Pty Ltd was contracted was undertaken for the client and its consulting advisers, and for review by regulatory agencies. The report should not be used by other parties without the consent of Groundwater Consulting Services Pty Ltd due to the potential for misunderstandings to occur.

11. APPENDICES

Appendix A – Figures

Appendix A

Figures

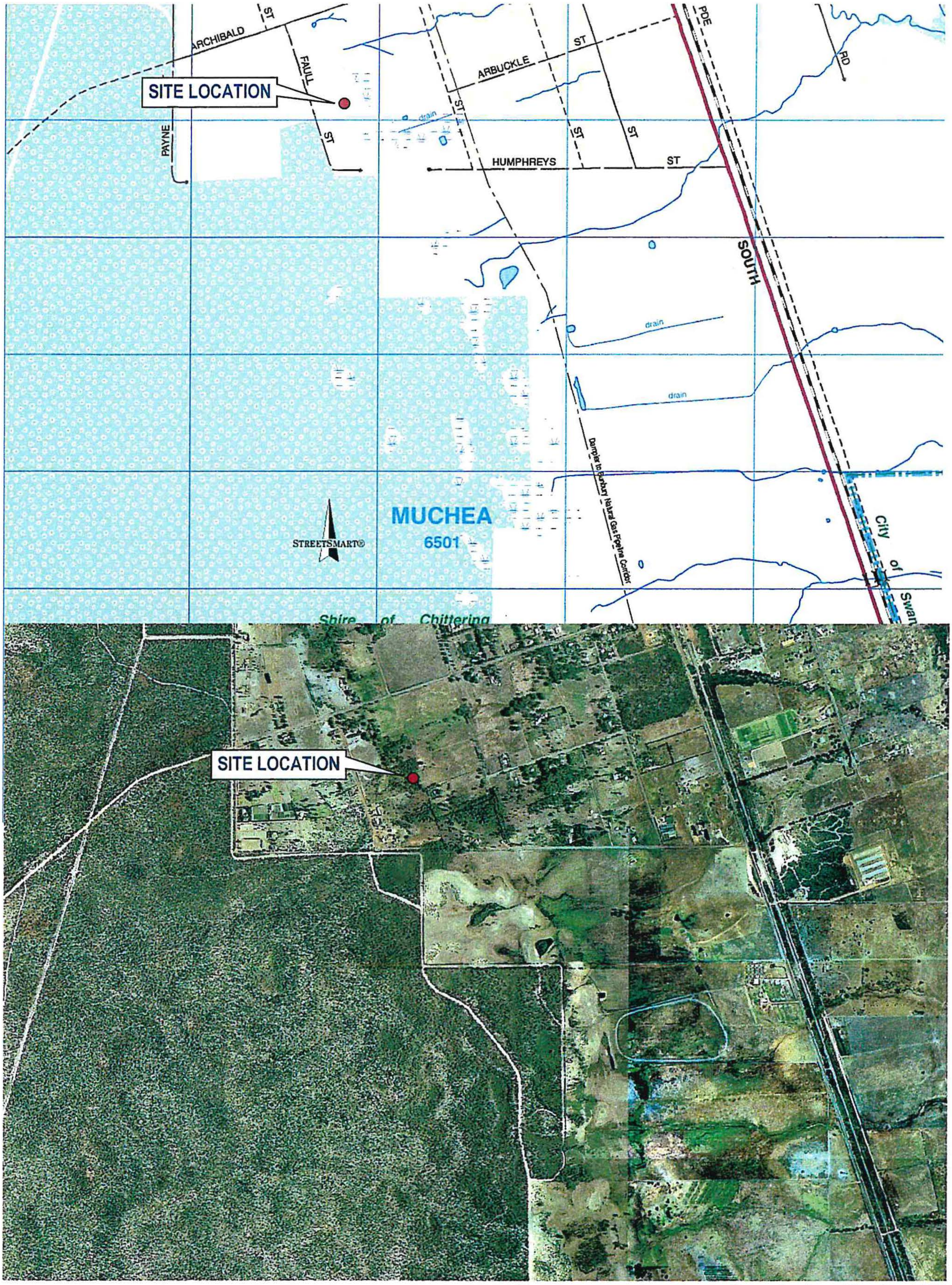


GCS/CALM004/Figure 1/September 2002.fh8

GCS Groundwater Consulting Services Pty Ltd

Figure 1:	*SITE LOCATION*
Location:	*Bullsbrook, Muchea, Egerton*
Drawing Date:	*October 2002*
Projection:	*AMG*
Client:	*CALM*
File Name:	*CALM004*

0 2000m



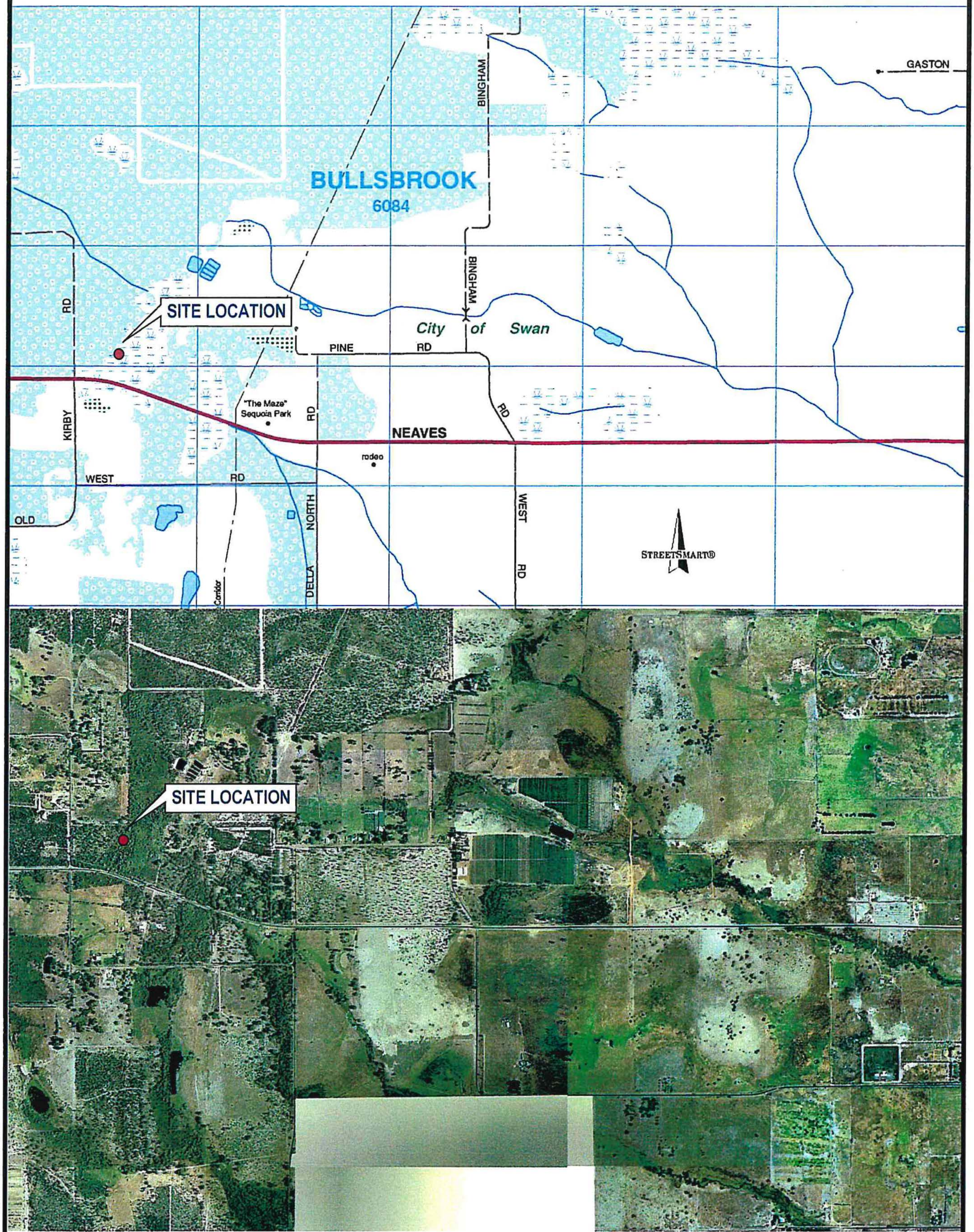
Source: Courtesy of StreetSmart 2002

GCS/CALM004/Figure 2/September 2002.fh8

GCS Groundwater Consulting Services Pty Ltd

Figure 2:	*SITE LOCATION - MUCHEA SPRINGS*
Location:	*Bullsbrook, Muchea, Egerton*
Drawing Date:	*October 2002*
Client::	*CALM*
File Name:	*CALM004*

0 500m



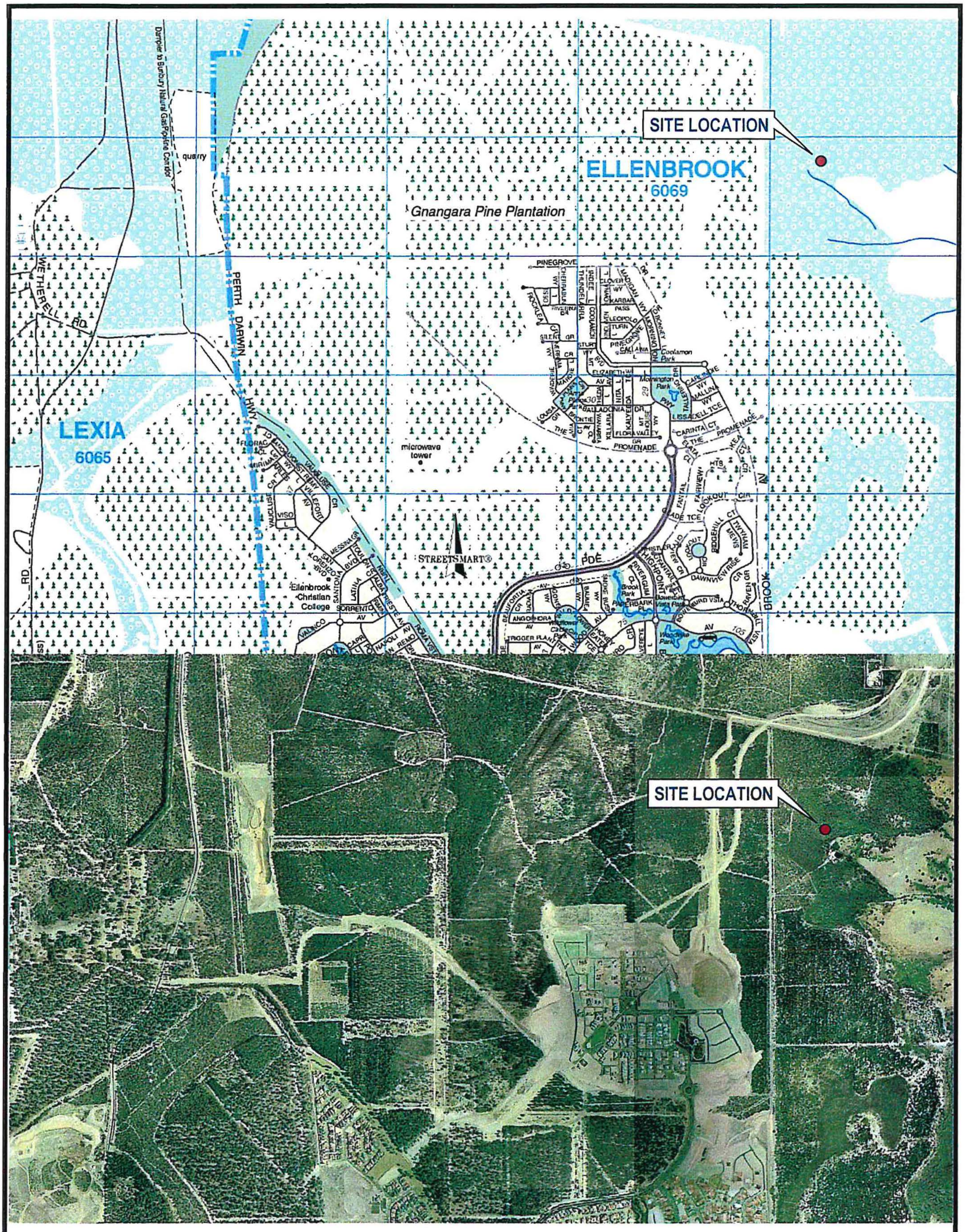
Source: Courtesy of StreetSmart 2002

GCS/CALM004/Figure 3/September 2002.fh8

GCS Groundwater Consulting Services Pty Ltd

Figure 3:	*SITE LOCATION - BULLSBROOK SPRINGS*
Location:	*Bullsbrook, Muchea, Egerton*
Drawing Date:	*October 2002*
Client:	*CALM*
File Name:	*CALM004*

0 500m

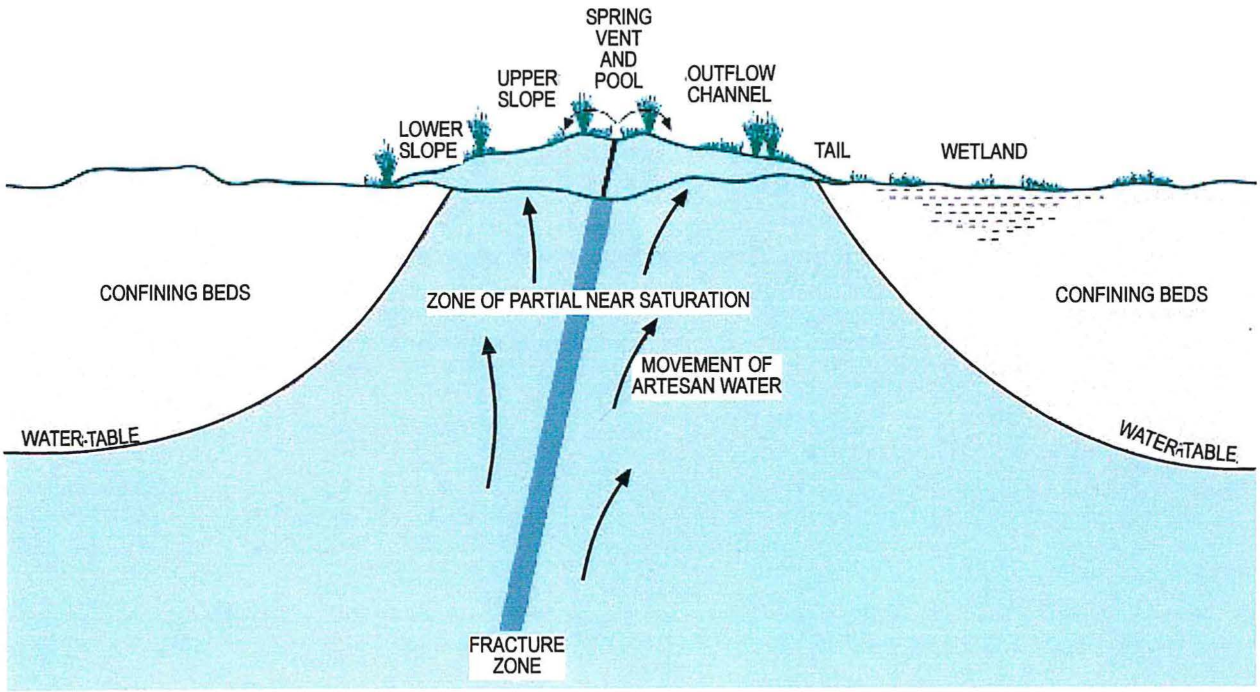


GCS/CALM004/Figure 4/September 2002.fh8

GCS Groundwater Consulting Services Pty Ltd

Figure 4:	*SITE LOCATION - EGERTON SPRINGS*
Location:	*Bullsbrook, Muchea, Egerton*
Drawing Date:	*October 2002*
Client:	*CALM*
File Name:	*CALM004*

0 500m

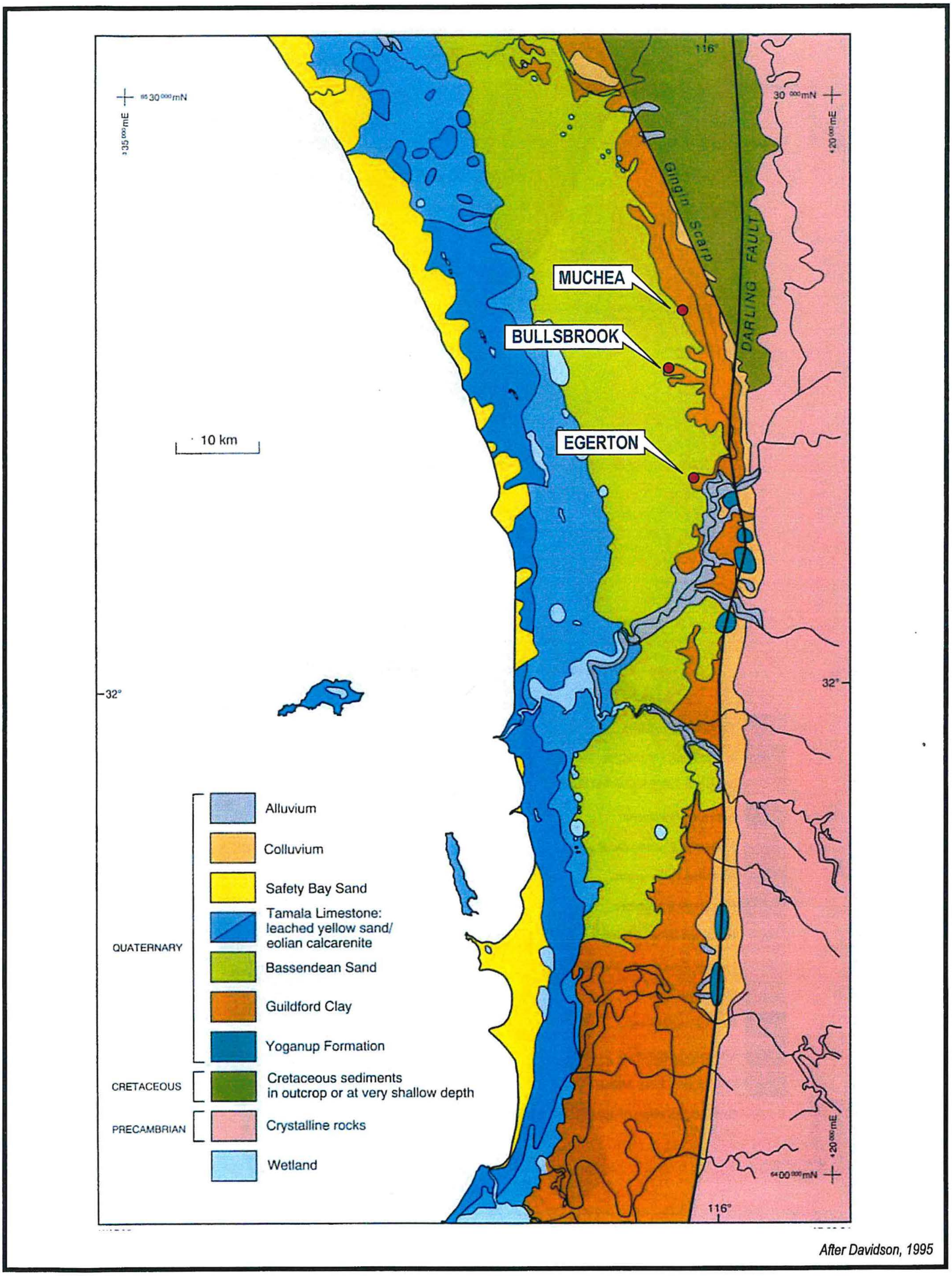


After Keane, 1997

GCS/CALM004/Figure 5/September 2002.fh8

GCS Groundwater Consulting Services Pty Ltd

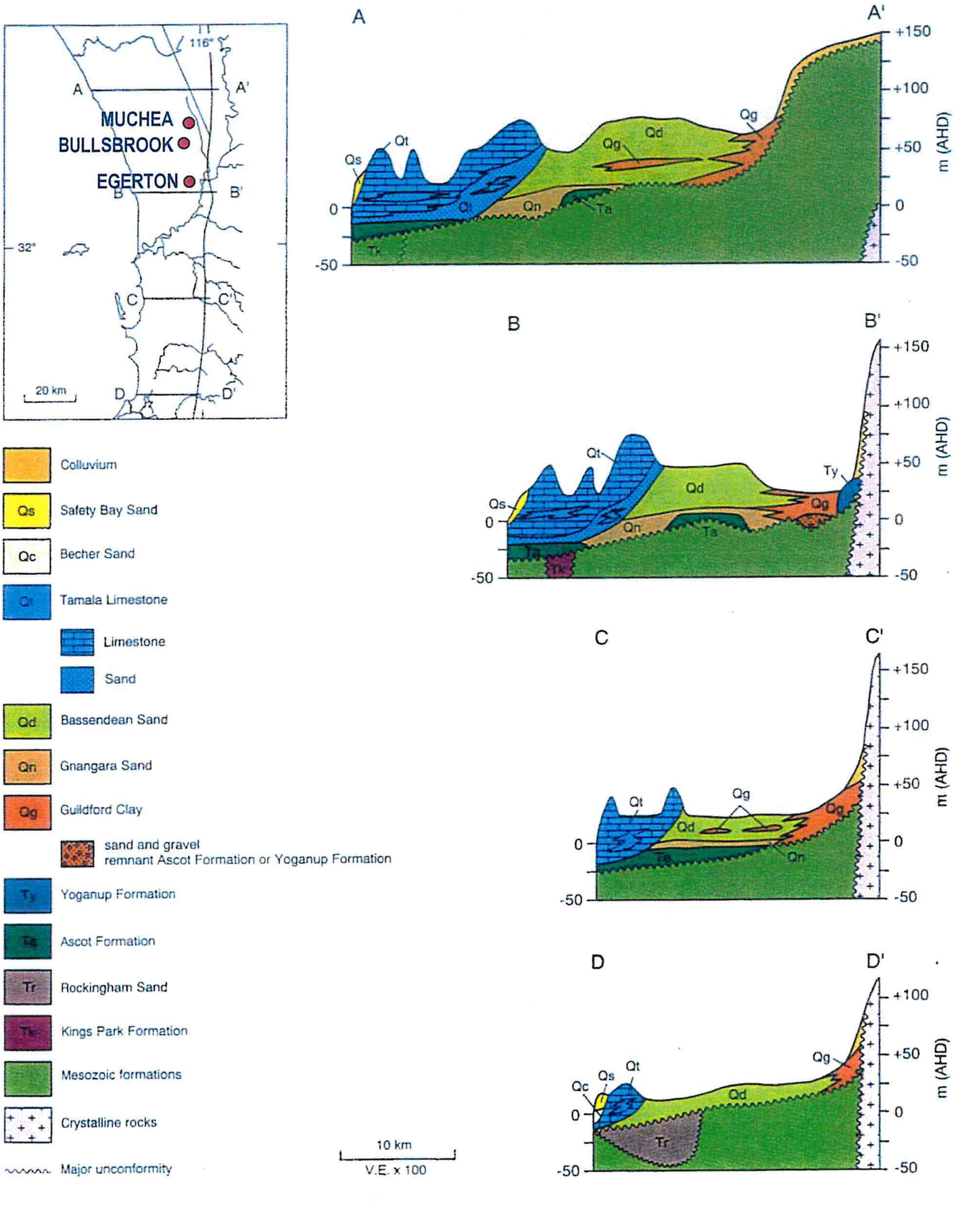
Figure 5:	*CROSS SECTION OF A TYPICAL MOUND SPRING - GREAT ARTESIAN BASIN*
Drawing Date:	*October 2002*
Location:	*Bullsbrook. Muchea, Egerton*
Client:	*CALM*
File Name:	*CALM004*



GCS/CALM004/Figure 6/September 2002.fh8

GCS Groundwater Consulting Services Pty Ltd

Figure 6:	*SURFACE GEOLOGY*
Location:	*Muchea, Bullsbrook, Egerton*
Drawing Date:	*October 2002*
Projection:	*AMG*
Client:	*CALM*
File Name:	*CALM004*

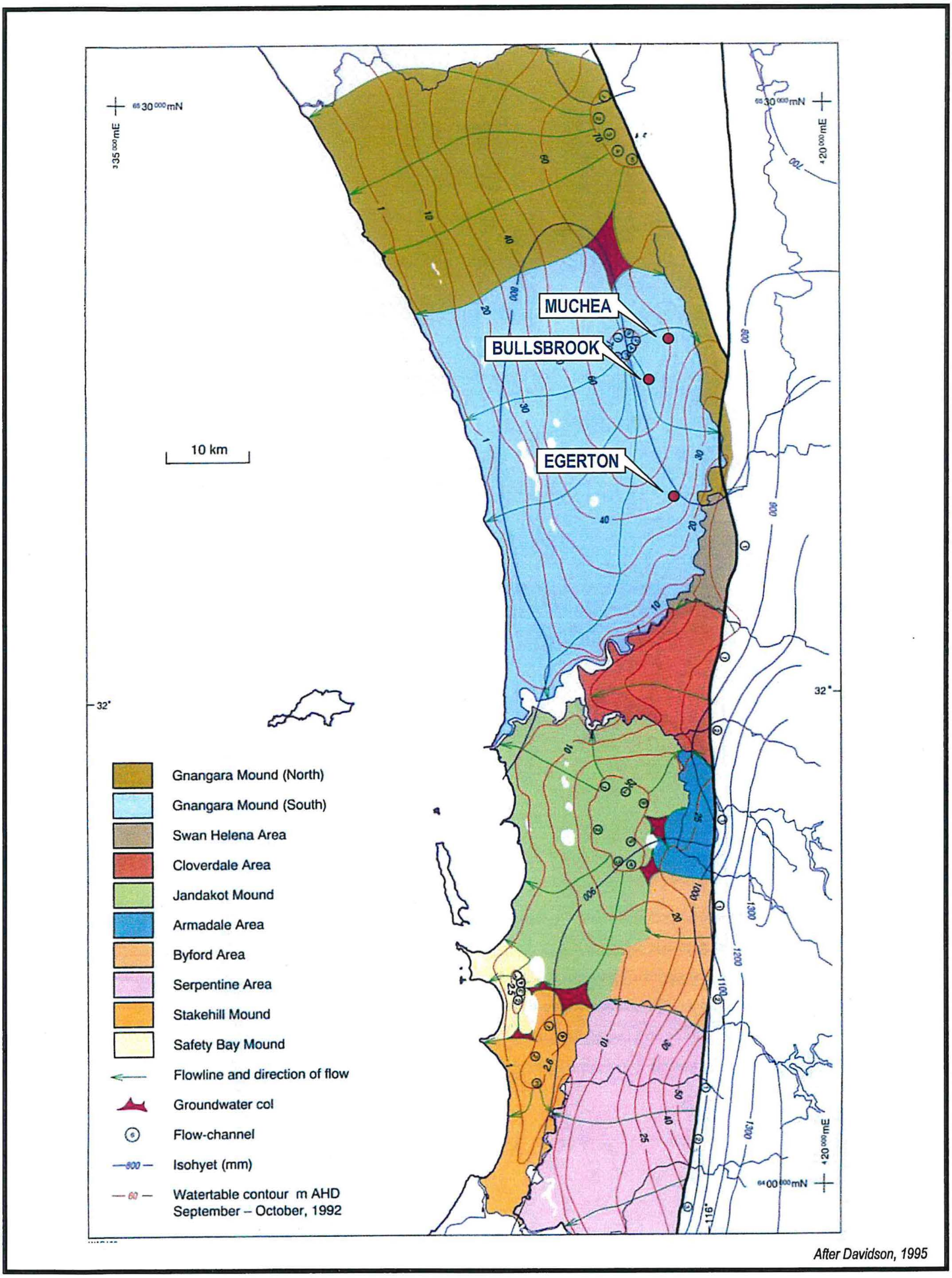


After, Davidson 1995

GCS/CALM004/Figure 7/October 2002.fh8

GCS Groundwater Consulting Services Pty Ltd

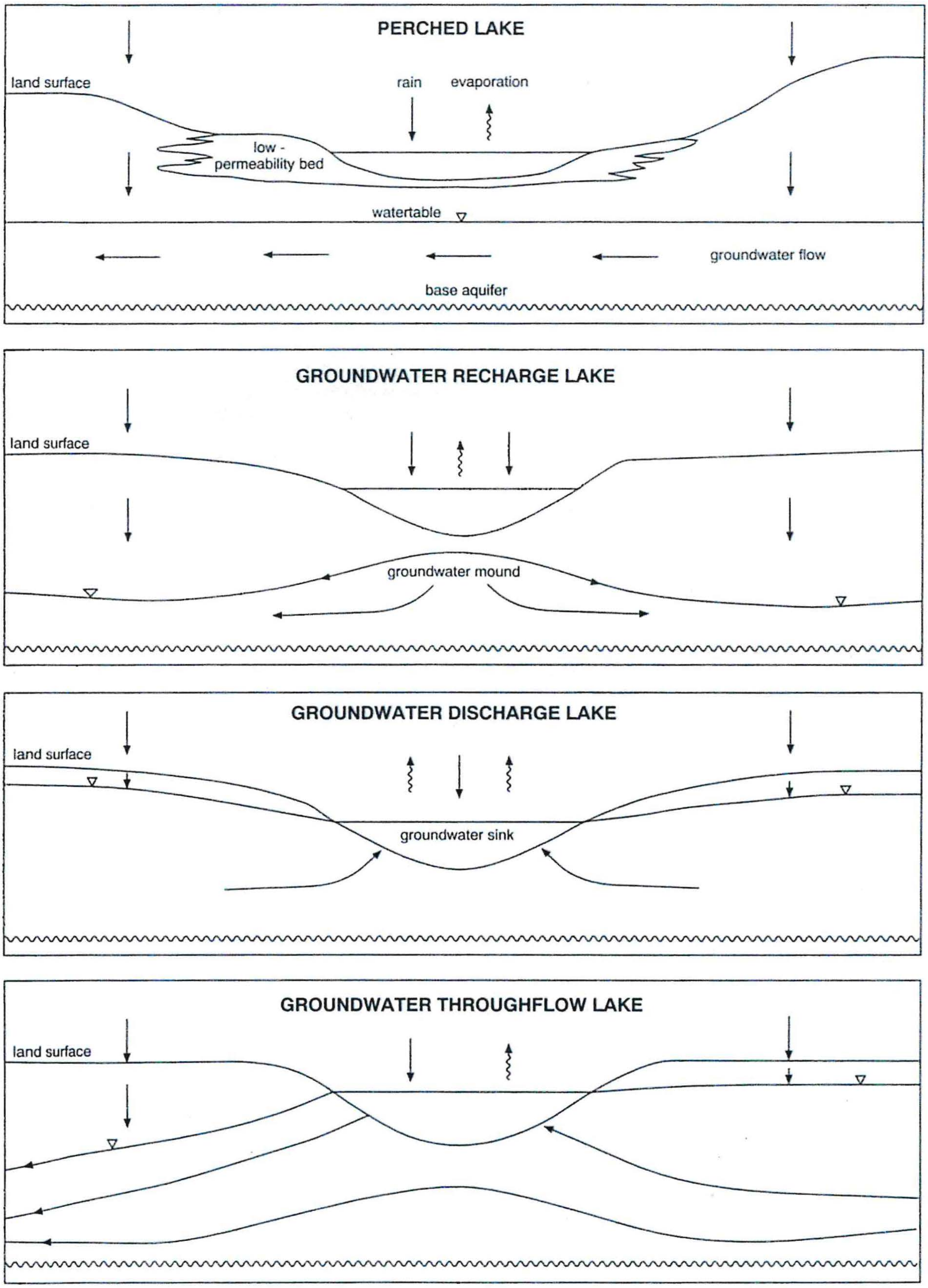
Figure 7:	*LOCAL CROSS SECTIONS*
Location:	*Muchea, Bullsbrook, Egerton*
Drawing Date:	*October 2002*
Client:	*CALM*
File Name:	*CALM004*



GCS/CALM004/Figure 8/September 2002.fh8

GCS Groundwater Consulting Services Pty Ltd

Figure 8:	*GROUNDWATER TABLE ELEVATION & FLOW DIRECTIONS*
Location:	*Muchea, Bullsbrook, Egerton*
Drawing Date:	*October 2002*
Projection:	*AMG*
Client:	*CALM*
File Name:	*CALM004*

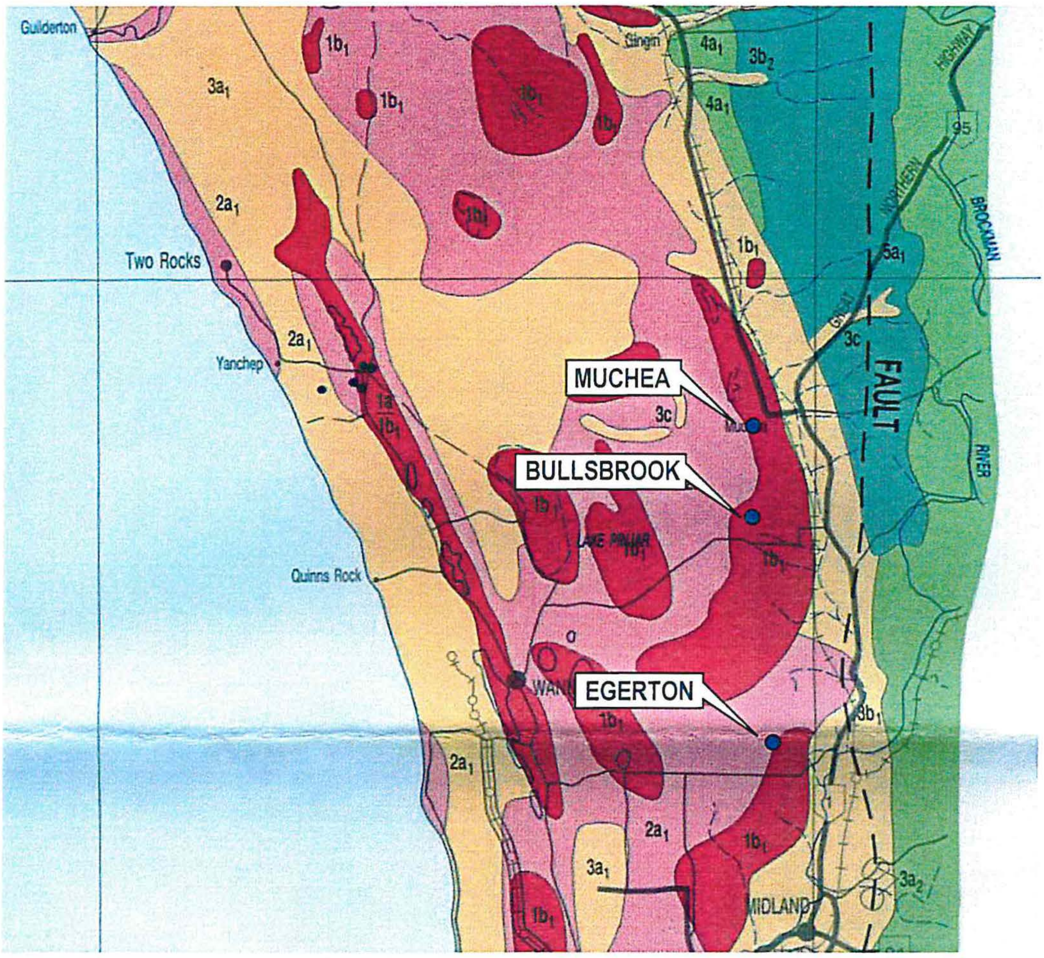


After Davidson, 1995

GCS/CALM004/Figure 9/September 2002.fh8

GCS Groundwater Consulting Services Pty Ltd

Figure 9:	*SWAN COASTAL PLAIN WETLAND TYPES*
Location:	*Muchea, Bullsbrook, Egerton*
Drawing Date:	*October 2002*
Client:	*CALM*
File Name:	*CALM004*



1. VERY HIGH VULNERABILITY
   - 1a. Limestone: with known karst features
   - 1b. Sand, peat, and clay deposits (wetland areas): with a shallow water table (< 3 m)

2. HIGH VULNERABILITY
   - 2a. Sand, limestone: with a shallow to intermediate water table (5 — 30 m)
   - 2b. Fractured rocks: with a high permeability and a shallow to intermediate water table (3 — 30 m) (North Sheet only)

3. MODERATE VULNERABILITY
   - 3a. Sand, sandstone, limestone: with a deep water table (> 30 m)
   - 3b. Clay and minor sand: with a shallow water table (< 3 m)
   - 3c. Weathered and fractured rocks: with a moderate permeability and a shallow to intermediate water table (3 — 30 m) (North Sheet only)

4. LOW VULNERABILITY
   - 4a. Interbedded sandstone, siltstone, and shale: with a deep water table (> 30 m)
   - 4b. Shale and minor sandstone: with a low permeability and a shallow to intermediate water table (3 — 30 m) (North Sheet only)
   - 4c. Weathered and fractured rocks: with a low permeability and a shallow to intermediate water table (3 — 30 m)

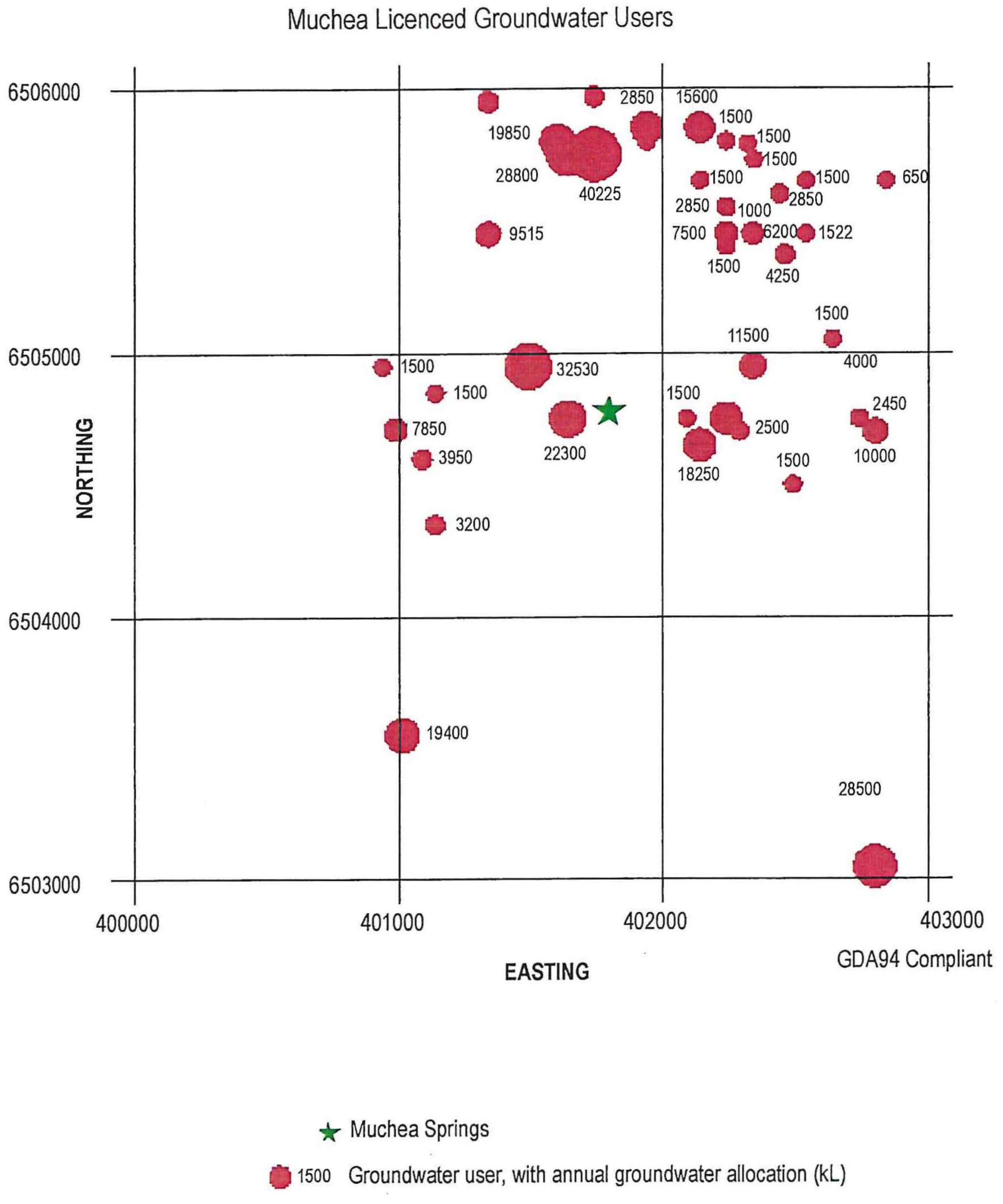
5. VERY LOW VULNERABILITY
   - 5a. Shale: thick units (> 30 m) with a low permeability; water table may be absent
   - 5b. Weathered and fractured rocks: with a very low permeability; water table may be absent

After Appleyard, 1993

GCS/CALM004/Figure 13/September 2002.fh8

GCS Groundwater Consulting Services Pty Ltd

Figure 10:	*GROUNDWATER VULNERABILITY TO CONTAMINATION*
Location:	*Muchea, Bullsbrook, Egerton*
Drawing Date:	*October 2002*
Projection:	*AMG*
Client:	*CALM*
File Name:	*CALM004*

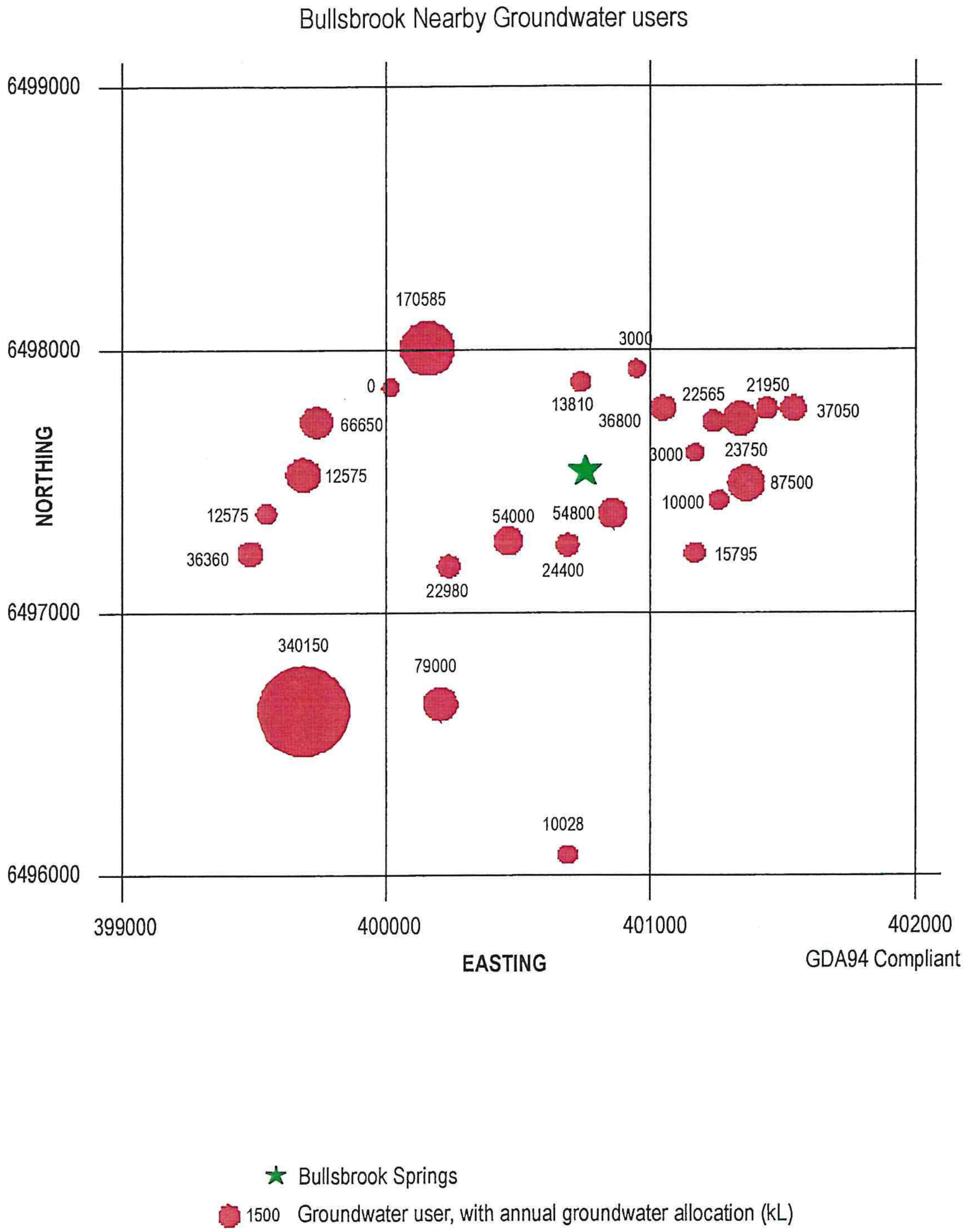


GCS/CALM004/Figure10/October 2002.fh8

GCS Groundwater Consulting Services Pty Ltd

Figure 11: *LOCAL GROUNDWATER USE - MUCHEA*

Location: *Bullsbrook, Muchea, Egerton*
Drawing Date: *October 2002*
Client: *CALM*
File Name: *CALM004*

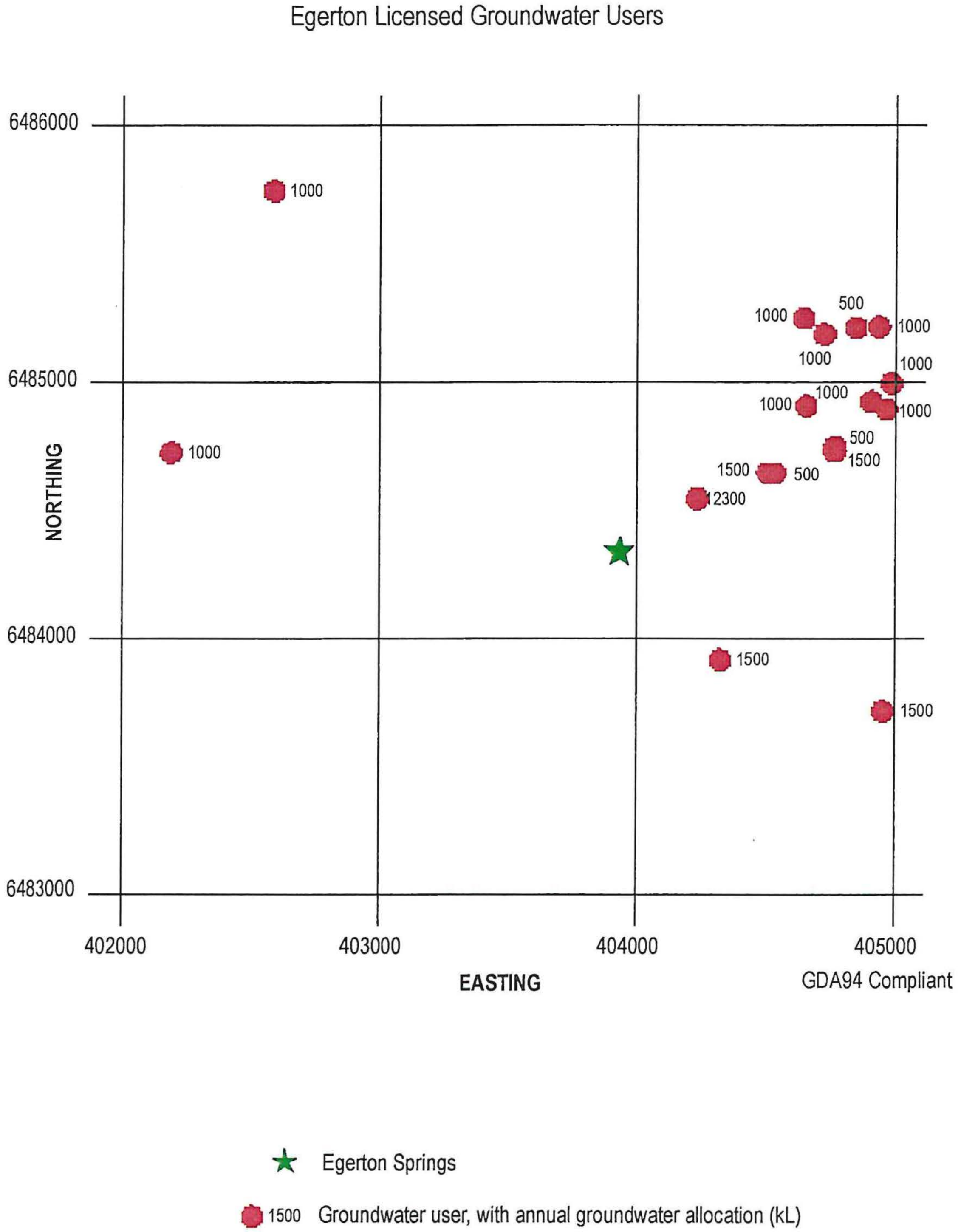


GCS/CALM004/Figure11/October 2002.fh8

GCS Groundwater Consulting Services Pty Ltd

Figure 12: *LOCAL GROUNDWATER USE - BULLSBROOK*

Location:	*Bullsbrook, Muchea, Egerton*
Drawing Date:	*October 2002*
Client:	*CALM*
File Name:	*CALM004*

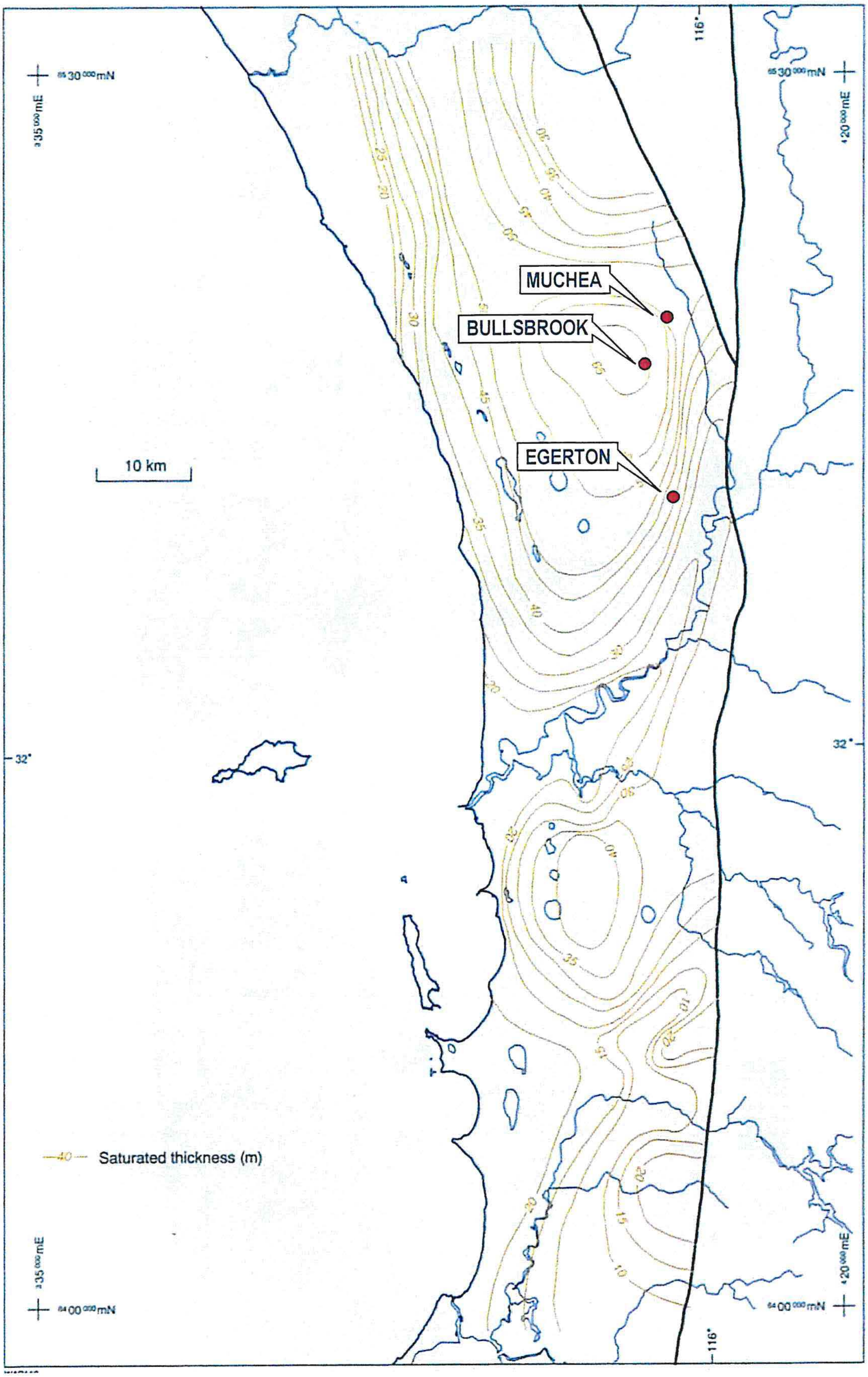


GCS/CALM004/Figure12/October 2002.fh8

GCS Groundwater Consulting Services Pty Ltd

Figure 13: *LOCAL GROUNDWATER USE - EGERTON*

Location:	*Bullsbrook, Muchea, Egerton*
Drawing Date:	*October 2002*
Client:	*CALM*
File Name:	*CALM004*



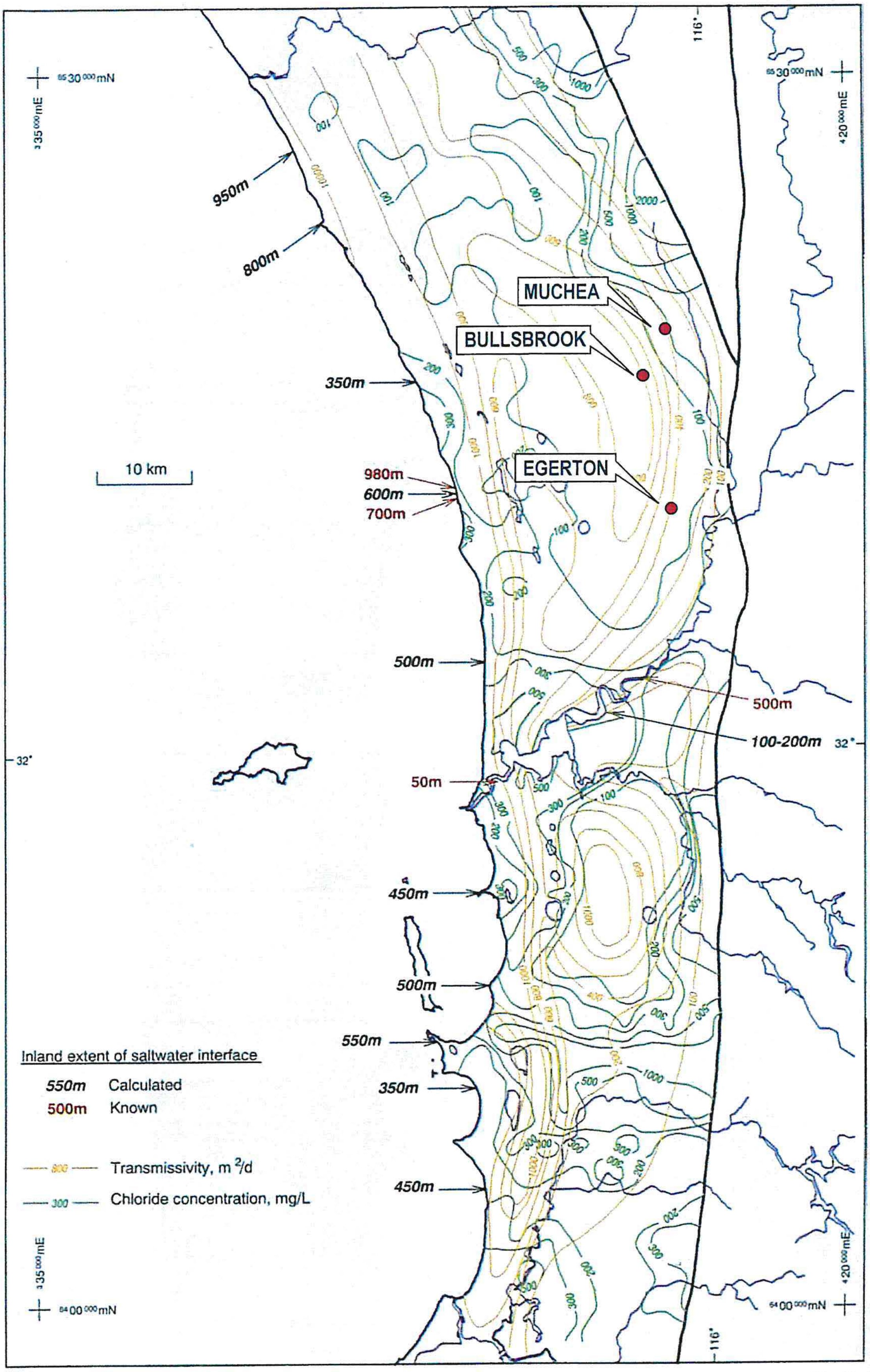
After Davidson, 1995

GCS/CALM004/Figure16/September 2002.fh8

Groundwater Consulting Services Pty Ltd

Figure 14: SUPERFICIAL FORMATIONS AQUIFER SATURATED THICKNESS

Location: Muchea, Bullsbrook, Egerton
Drawing Date: October 2002
Client: CALM
File Name: CALM004



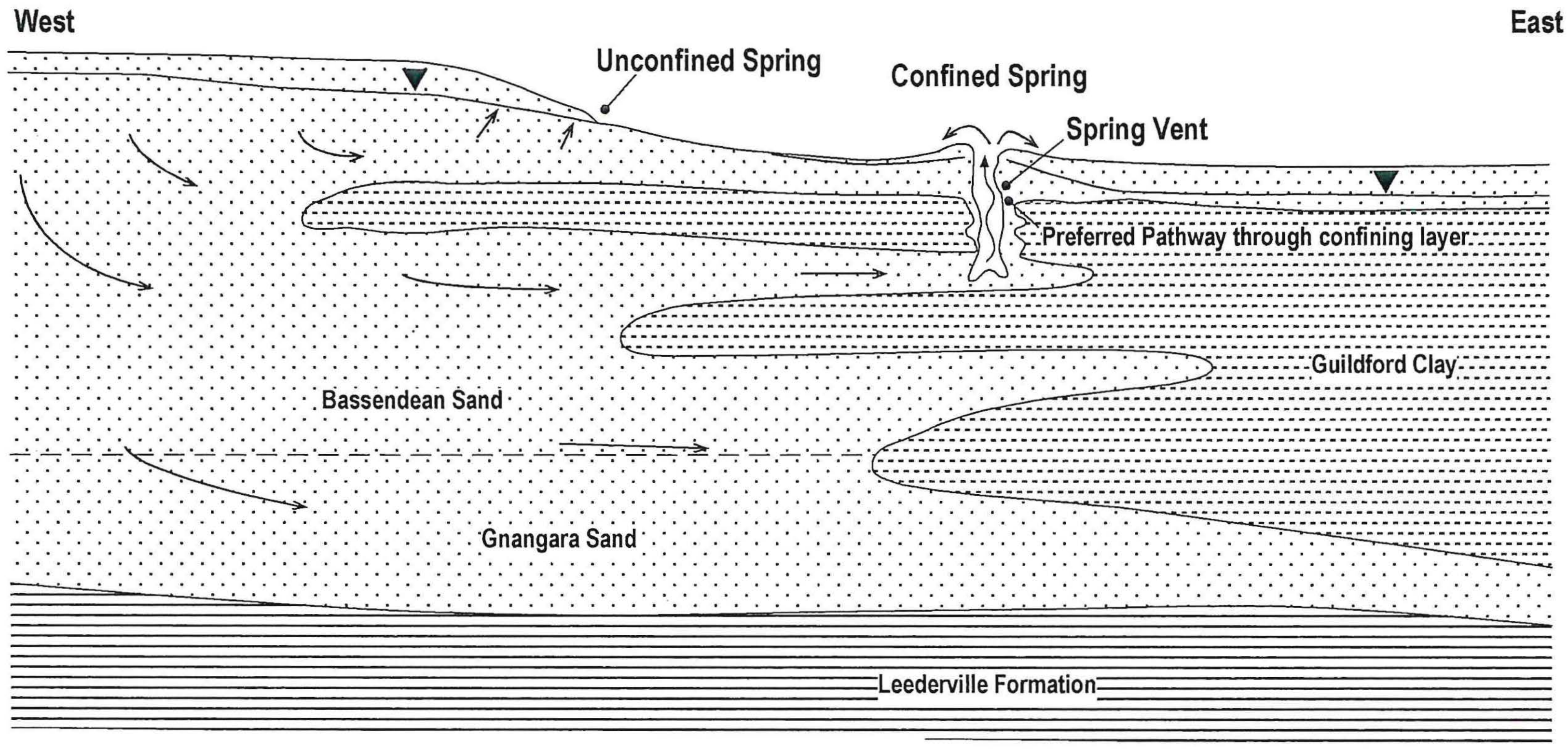
After Davidson, 1995

GCS/CALM004/Figure17/September 2002.fh8

GCS Groundwater Consulting Services Pty Ltd

Figure 15: SUPERFICIAL FORMATIONS AQUIFER TRANSMISSIVITY & CHOLORINITY

Location:	Muchea, Bullsbrook, Egerton
Drawing Date:	October 2002
Client:	CALM
File Name:	CALM004



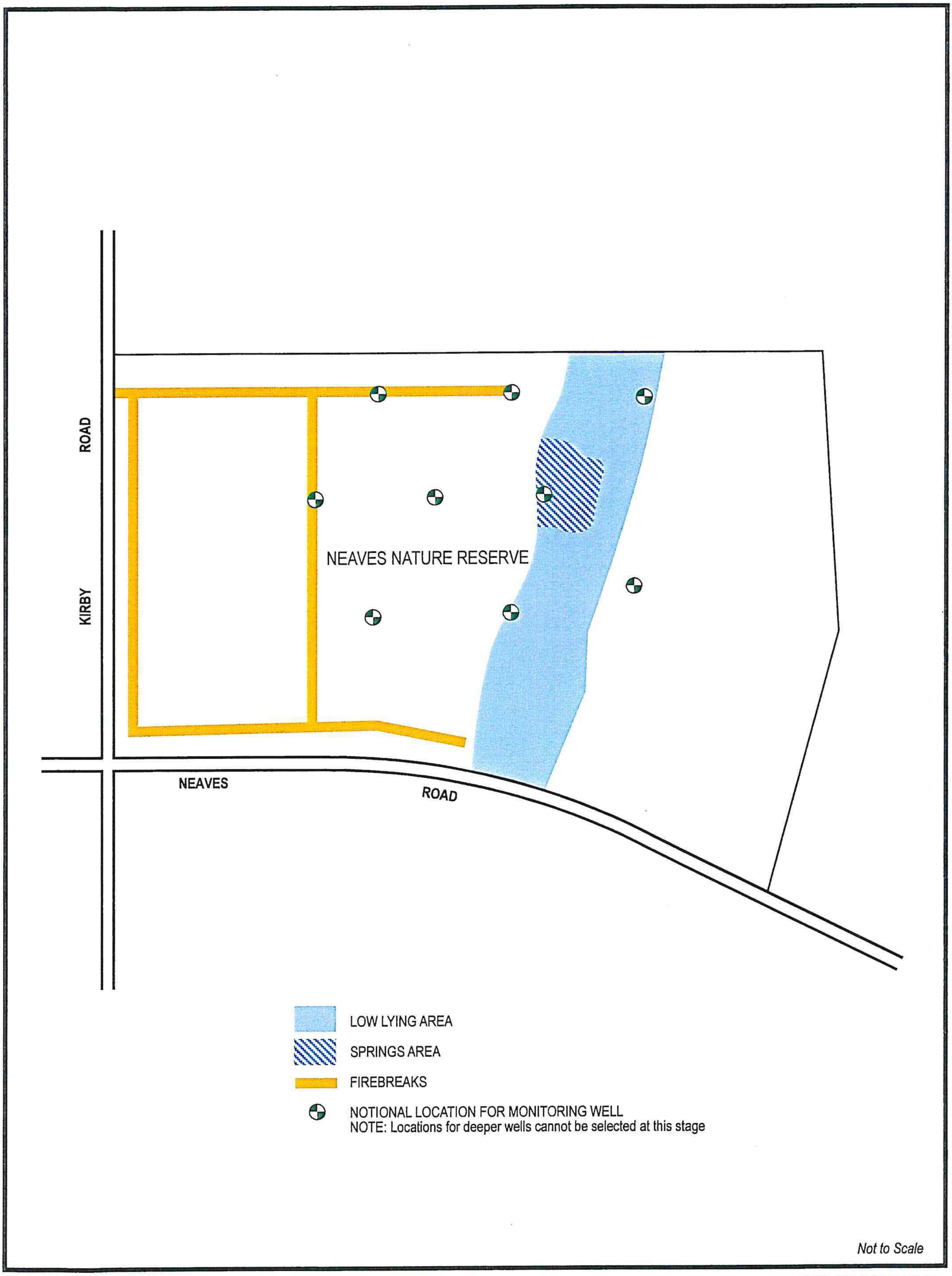
GCS/CALM004/Figure15/September 2002.fh8

GCS Groundwater Consulting Services Pty Ltd

▼ GROUNDWATER FLOW DIRECTION

⤻ WATER TABLE

Figure 16:	*HYDROGEOLOGY OF THE SWAN COASTAL PLAIN SPRINGS*
Location:	*Muchea, Bullsbrook, Egerton*
Drawing Date:	*October 2002*
Client:	*CALM*
File Name:	*CALM004*



GCS/CALM004/Figure14/September 2002.fh8

GCS Groundwater Consulting Services Pty Ltd

Figure 17: *PROPOSED SHALLOW DRILLING PROGRAMME*
Location: *Muchea, Bullsbrook, Egerton*
Drawing Date: *October 2002*
Client: *CALM*
File Name: *CALM004*