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Department of Conservation and Land Management

Preliminary Hydrogeological Investigation
Arinya Springs
Dowerin, Western Australia

FINAL

Project Number: *CALM007*

Report Date: *May 2003*

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1. INTRODUCTION

The Department of Conservation and Land Management (CALM) has a special interest in a unique saline spring environment located on private land in the Dowerin Shire (*Figure 1, Appendix A*). The spring occurs on the flank of, and discharges into Cunjardine Creek, which is a tributary of the Mortlock River. The Cunjardine Creek was originally named "Salt River" *(Figure 2, Appendix A)*, and this name appears on several older maps, however appears to have been dropped from common usage in favour of Cunjardine Creek.

The spring complex comprises a region of springs, which support an estuarine-type ecosystem. This investigation was focused on investigating the cause of the spring discharge, in order to assist CALM to identify and subsequently manage any threats to the ecosystem.

1.1 SETTING

The springs, and the drainage line into which they discharge, are all located within privately held agricultural land. The property owners have a long history on the property which appears likely to continue. The springs have always been an important part of the property and the owners are committed to protecting the springs.

Agricultural land-use on Arinya and adjoining properties has probably induced groundwater levels to rise. Some wetlands on the property have increased in size and become more saline. Normal agricultural practices including application of fertilizers, herbicides and pesticides are assumed to be undertaken on the arable land on the property.

1.2 HISTORY

The surveyor Austen named the creek into which the springs discharge "Salt Creek" in 1858, and it is presumed that the springs were the source of this saline water. The springs were therefore assumed to be discharging brackish or saline water when the first settlers cleared the area.

The surrounding area was cleared between the 1930s and 1950s for agriculture, and currently supports cereal cropping and sheep grazing.

The spring flows and salinity, although not formally monitored, have not changed noticeably, either in living memory or seasonally, based on the observations of the landowner.

The Department of Conservation and Land Management's Scientific Advisory Committee have classified the flora assemblage of the dunes, sand-plain, saline seep, flats and flow lines, and margins of the creek as a Vulnerable Threatened Ecological Community, due to the uniqueness of the ecosystem flora assemblage. Investigation of the hydrogeology of the springs is required to assist CALM to manage and protect the springs, which are seen as the most vulnerable component of the assemblage.

Groundwater Consulting Services completed a preliminary inspection of the springs in August 2002 to develop the scope of work for this project. The preliminary inspection concluded that the system driving the springs has discharged groundwater for at least several thousand years, and that there was no evidence of changes in water flows or quality. The occurrence, and impact, of relatively recent changes in land-use on the hydrogeology, hydrology and ecology of the springs, however, was unknown.

2. SCOPE OF WORK

This project comprised investigation of the regional and local geology and hydrogeology, and their controls on the spring system.

The following major tasks were completed:

- Obtain and review geological maps, topographic maps, aerial photographs (stereoscopically), satellite imagery and bore data;
- Review any available local groundwater records and conduct limited interviews with local landholders and government agencies to assess any overall trends in groundwater level or quality variations;
- Develop a conceptual model of the regional geology and hydrogeology including the igneous/metamorphic geology (the granitic basement rocks), sedimentary geology (including shallow sand-plains and any palaeochannel deposits), the relationships between the units, and any major structural deformation or faulting;
- Map the spring area including the following aspects:
  - Utilisation of a GPS unit to survey point locations for features of interest (estimated +/- 10m);
  - Identify/categorise individual groundwater discharge features and estimate flows;
  - Test the water salinity and hydrochemistry (field testing for pH, electrical conductivity and temperature; and laboratory analyses for pH, electrical conductivity, salinity, total iron, Na, K, Ca, Mg, Cl, NO3, SO4, HCO3 and CO3);
  - Map the surface geology (including chemical precipitates and spring-discharge sediments) to include the upper 0.1-0.2m of the soil profile – deeper excavation may induce spring flows to occur;
  - integrate the above with mapping of the vegetation zonation (by the Department);
- Prepare and submit a bound report providing:
  - data summaries;
  - geological/hydrogeological cross-sections and maps as required;
  - discussion of the work undertaken and presentation of the possible mechanisms that support the springs and
  - recommendations and designs for further investigations, if appropriate.

The overall objective of the project was to investigate the hydrogeology with a view to managing and protecting the threatened ecological community, and this was the theme of the investigation and report.

A photographic record of relevant aspects of the springs was collected during the site works.

3. DRAINAGE, GEOMORPHOLOGY AND SOILS

3.1 DRAINAGE AND GEOMORPHOLOGY

The springs lie on the northern bank of a bend in Cunjardine Creek. The spring discharge coincides with a change in the character of the river from a small, ephemeral slow-flowing drainage with poorly developed riparian vegetation to a permanent creek with a wide, flat floor and significant ecosystem. *Figure 3 (Appendix A)* presents an aerial view of the springs.

The springs occur on the western side of a drainage divide. The drainage divide represents the line of landscape rejuvenation, and is advancing eastward as a result of headward erosion in the externally-draining catchments.

The western catchment is part of the Mortlock River (North Branch) catchment, which drains externally to the Indian Ocean via the Avon and Swan Rivers. The Mortlock river has been severely affected by dry-land salinisation in the region which results in increased flows and higher water salinity, especially in the drier months.

The eastern catchment has internal drainage towards a chain of salt lakes. The eastern catchment once supported an ancient drainage system with large rivers, which drained towards an internal lake in the south and east of Western Australia. This catchment would have originally extended to the west of the current drainage divide.

Reduction in rainfall over millions of years resulted in gradual drying and filling of the ancient internal river systems, and deposition of fine-grained (clay and silt) sediments over the sandy and gravely riverbed sediments. These ancient river systems, which no longer function as rivers, are known as palaeodrainages.

Palaeodrainages are easily identified by chains of salt lakes occupying broad, flat valleys. The major drainages are the most obvious, and it becomes progressively more difficult to identify the smaller tributaries.

3.2 SOILS

The Mortlock River catchment comprises undulating sandy and gravely loam soils developed on a granite lateritic weathering profile. Granitic bedrock has weathered to form a clay-rich gritty saprolite, which was capped by a continuous veneer of concentrated iron oxides and hydroxides (laterite). The laterite capping has mostly eroded, and the current land surface comprises a combination of erosional surfaces and residual sand and gravel deposits. Minor alluvial deposits occur at drainage lines.

4. HYDROGEOLOGY

4.1 TYPICAL HYDROGEOLOGY OF THE DARLING PLATEAU

Groundwater in the Darling Plateau occurs in four major settings:

- Fractured bedrock
- Granular saprolite
- Surficial deposits
- Palaeochannel sediments

4.1.1 Landscape Development

Bedrock on the Darling Plateau typically comprises granite-based rocks, with localised greenstone belts, containing a variety of metamorphosed volcanic and sedimentary rocks. The bedrock has been deeply weathered (to form a thick layer of sandy clay and clay) and eroded by drainage systems. The chemical alteration and physical transfer of materials within the landscape forms the present land-surface. Laterite (iron-oxide cemented soils) occur on ancient plateaus and have been themselves erodes to form breakaways.

Soils (the surface and shallow subsurface geological materials) can be developed on fresh and weathered bedrock, sediments and laterite.

4.1.2 Fractured Bedrock

Fractured bedrock aquifers occur where joints, fractures, faults or shear zones allow movement of groundwater through otherwise impermeable bedrock. The aquifers are typically thin, vertical planar features which occur in sub-parallel or cross-cutting sets, or are associated with major geological structures. The aquifer occurrence is often strongly controlled by the geological structures, and to a lesser extent by the rock-type. These aquifers may be essentially absent over large areas of undeformed bedrock.

4.1.3 Granular Saprolite

The base of the lateritic weathering profile comprises a thin or variable-thickness layer of decomposing granite, where the grain-contacts have broken but the grains (mineral crystals) are intact. Granular saprolite is often seen around granite outcrops as a friable rock that disintegrates when dropped onto the ground. The aquifer becomes less permeable at shallower depths due to plugging with clayey weathering products, and also at greater depths where the grain-contacts are un-broken. The aquifer can be well developed (thicker and more permeable) at geological faults and related structures.

4.1.4 Residual Deposits

Shallow surface deposits of sand and gravel, moved by the action of wind or water (or both) can result in thin, perched aquifers. These are usually localised, and restricted to either a portion of a hill-slope or a drainage line, and may become unsaturated in periods of low rainfall.

4.1.5 Palaeochannel Sediments

Palaeochannels are the relict sediments that were deposited in ancient river systems that transected the interior landscape during wetter climatic conditions in the Tertiary. The channels were initially in-filled with coarse (sand and gravel) deposits and as they become sluggish and dried out, finer grained (silt and clay) deposits were laid down.

Palaeochannels are commonly associated with chains of salt lakes which have existed prior to clearing of the land. These salt lakes have often become enlarged (and new salt lakes have formed) as a result of clearing. However, they have acted as groundwater sinks (discharging groundwater by evaporation) for several millions of years, and as a result have accumulated large quantities of salt and saline groundwater.

4.2 HYDROGEOLOGY OF THE STUDY AREA

The region around the springs is known or likely to contain each of the aquifer types identified above. A brief discussion follows.

4.2.1 Fractured Bedrock

These aquifers occur along fault lines that are subtle, but detectable, on both aerial photographs (on a local scale) and on satellite imagery (on a regional scale). *Figure 4 (Appendix A)* shows interpreted faults or fractures, and it is likely that some of these features represent relatively permeable conduits in the bedrock. These structures may not, however, represent zones of significant groundwater movement.

4.2.2 Granular Saprolite

The saprock aquifer will occur as a relatively continuous aquifer overlying the bedrock, and will be truncated where fresh bedrock reaches the surface at outcrops. This aquifer is in hydraulic connection with the fractured bedrock aquifers, and is often developed by hand-dug wells near granite outcrops.

4.2.3 Residual Deposits

Sand-plain aquifers occur within the region and are mapped on hillsides. A thin sand-plain aquifer has been developed by the owners of Arinya for small-scale irrigation water for a plant nursery. The aquifer also supports local wetlands and is commonly developed by shallow wells in the wheat-belt.

4.2.4 Palaeochannel aquifers

A major palaeochannel has been identified approximately 10km to the north and east of the springs, and oriented north-west to south-east. It includes Dowerin Lake and the Nambling Flats, and forms part of a palaeodrainage system which originally drained towards the Cowcowing Lakes area.

4.3 DRYLAND SALINISATION

Dryland salinisation is widespread in the wheat-belt. Salinisation occurs intensively in areas nearer the Mortlock River, and the intensity generally reduces with distance towards the catchment divide. The springs lie high in the catchment, several kilometres west of the divide.

Groundwater levels and salinity in the wetlands supported by the sand-plain aquifer are thought to have risen since clearing. However, salinisation is not well developed in comparison to properties in lower areas in the landscape.

Stressed vegetation was observed adjacent to Cunjardine Creek (on the south bank), and this is attributed to rising groundwater levels beneath the adjacent cleared farmland.

4.4 LOCAL GROUNDWATER USE

Groundwater use is locally restricted to shallow bores and dug wells which supply small volumes of stock and domestic water for on-farm use. Irrigation supply for a small nursery is currently obtained from scheme supply, but is hoped to be drawn from bores drawing fro the sand-plain aquifer to the north of the homestead on Arinya in the near future.

Other than the springs and associated ecosystem, small wetlands on the property are supported by groundwater. It is thought that most of the wetlands are supported by the sand-plain aquifer.

Local groundwater use is considered to be negligible, however the environmental and stock/domestic uses place a high value on groundwater in the sand-plain aquifer.

5. REGIONAL MAPPING, SATELLITE DATA AND AERIAL PHOTOGRAPHY

5.1 GEOLOGICAL MAPPING

Geological mapping is available at 1:250,000 scale and shows only broad variations in bedrock lithology (*Figure 3, Appendix A*). The mapped rock units provide no indications of the cause of the springs, and the scale of mapping is too broad to highlight the local variations that are thought to be important.

Local bedrock geology is mostly obscured by soil cover.

5.2 SATELLITE DATA

Features that were observed on the satellite data and aerial photographs may have been initially observed on one media and subsequently identified in the other.

Satellite data were obtained through the Department of Land Administration for a large area including the springs. A subset of the data, extending approximately 25km north-south and west-east, was cropped out of the image and includes all of the major features identifiable in the data *(Figure 4, Appendix A)*

The data included bands 1, 4 and 7 and a panchromatic band, at a resolution of approximately 12.5m. The data enable information on variations in chlorophyll content (reflected in vegetation), kaolin content (reflecting soil type) and surface moisture (reflecting lakes, wetlands and waterlogged areas). The combined image provides information on the natural features of the landscape.

5.3 AERIAL PHOTOGRAPHY

Aerial photographs were obtained as stereoscopic pairs for the springs location and an area approximately 10km around the springs, concentrated to the east and north.

The stereoscopic evaluation of the photographs allows the land surface to be seen in three dimensions, which allows topographic features to be identified. The landform is gently undulating in the area, and only subtle features were identifiable.

Figure 3 (Appendix A) is based on an high-resolution aerial photograph of the site and shows the site details clearly.

5.4 LINEAMENT ANALYSIS

An informal lineament analysis was conducted on the springs, as the Cunjardine Creek.

Lineaments represent linear features (such as tree-lines, drainage systems, soil-type changes, ridges etc) that may be related to underlying geological structures. They do not provide a clear indication of geology nor hydrogeology, however, they may indicate likely structural weaknesses in the bedrock, or changes in rock-type, and, may indicate preferential groundwater flow pathways or directions.

A strong indication of a zone of relatively intense fracturing or faulting was noted in a north-east to south-west direction *(Figure 4, Appendix A).* It controls the alignment of Cunjardine Creek about 20km to the south and west of the springs, becoming more subtle at the springs and to the north-east. These lineaments are thought to represent a zone of fractures or faults which extend across the catchment boundary.

There are a number of lineaments that may intersect at or near the location of the springs. It is currently thought that the location and orientation of Cunjardine Creek is strongly controlled by bedrock fractures, however they probably play a lesser role in the function of the springs.

6. SITE INSPECTION AND RESULTS

6.1 SITE INSPECTION

The springs and surrounding region were inspected on 7 and 8 January 2003.

The major objective of the site inspection was to map the springs with the intention of analysing any relationships between the morphology of the springs and the underlying mechanism controlling the springs. As more familiarity with the springs was gained, it became apparent that the springs themselves had significantly altered the geology and geomorphology of the site by both erosion and deposition of materials.

The mapping of individual spring flows was hoped to be used to identify different groundwater sources for what initially appeared to be separate mechanisms behind the springs.

6.2 HYDROCHEMISTRY

Figure 3 (Appendix A) shows the electrical conductivity, pH and temperature of groundwater measured at the springs. Some of the data are expected to have been affected by mixing, evaporative concentration and ambient warming. The groundwater ranges from brackish to saline, slightly acidic to slightly alkaline, and is cool. Variations in water quality can often be related to the nature of the measurement location within the system, however not all factors affecting the hydrochemistry are understood. Note that seawater has a salinity of approximately 35,000 mg/L Total dissolved solids, which is equivalent to an electrical conductivity of approximately 64,000 μS/cm.

Water samples from selected locations were collected and analysed by a NATA registered laboratory for standard hydrochemical parameters to allow hydrochemical typing to be conducted. The hydrochemical data are presented *(Figure 5, Appendix A)* on a Piper trilinear diagram, which presents each sample on a diamond-shaped field diagram, with separation between data points indicating different types of water. This presentation method is not affected by salinity and allows different sources of water, and their mixing products, to be identified.

The Piper diagram clearly shows that all of the groundwater samples collected at the springs fall in a tight group, and are dominated by sodium and chloride. The sample which falls on its own was from a stock-water soak on the property, and probably represents groundwater from the sand-plain aquifer.

The laboratory analytical report is provided in *Appendix B*.

6.3 GEOLOGY

The geology of the springs was mapped with particular reference to the geological units that were considered to be important to the formation and ongoing hydrogeology of the springs. A peat unit that occurred in the near-surface was mapped by excavation of shallow test-pits to a maximum depth of about 0.5m. The bottom of the peat was deliberately not exposed at most locations in case shallow artesian pressures were released, as it was evident that the peat was acting as a confining layer in the system.

"Micro-springs" were observed throughout the low-lying area, and walking on the ground surface provided sufficient extra hydrostatic pressure in the subsurface to make existing holes, which penetrated the peat, exude gas bubbles and water. The gas bubbles probably comprise carbon dioxide given off during decomposition of the peat. These holes, as well as larger spring vents, are probably tree or plant-root holes which have become conduits after decomposition of the vegetative matter.

Figure 6 (Appendix A) shows the mapped extent of the peat in the shallow subsurface.

6.4 PRESSURES

Two general spring forms were noted, slow seepage and free-flowing.

Slow seepages occurred generally on the higher ground, and were characterised by damp soil, salt crusts and halophytic vegetation – they mostly occurred in sandy soils. Areas of seepage were noted to change diurnally from slow free-flowing discharge during the cool morning to damp evaporative discharge during the hotter part of the day. The net groundwater discharge is probably higher during the heat of the day even though visible flows are smaller. These springs are thought to be due to direct seepage from the aquifer, which is exposed at the land surface.

Free flow from localised spring vents was noted in the lower lying areas of the springs system, and ranged from coalesced flows from sandy soils to discrete spring vents with rapid discharge (up to 3.2L/s of groundwater from a single vent). Free-flowing springs occurred within the mapped area of the peat deposit, and indicate higher pressures beneath the ground surface.

Where possible, spring flow rates were estimated based on average water velocity and average channel cross-sectional areas. Flow measurements are considered to be accurate to about 25-50% (depending on the characteristics of the measurement location). Spring flows are shown on *Figure 6 (Appendix A)*.

7. SYNOPSIS

The works completed in this project enabled the following discussion of various aspects of the springs to be developed. The statements represent the opinion of the author, based on experience, the background work completed and observations at the site.

7.1 REASON FOR LOCATION

It is thought that a palaeodrainage tributary (or palaeotributary) of the palaeochannel which includes Dowerin Lake originally flowed northwards. The palaeotributary eroded in a southerly direction, from the Nambling Road South Reserve area, to the present location of the springs, and it turned westerly through "little lake" (a small wetland which occurs west of the springs). Subsequent headward erosion in the Mortlock Catchment led to capture of that tributary by what is now Cunjardine Creek. The inferred location of the tributary is shown on *Figure 7 (Appendix A).*

Discharge of groundwater commenced when Cunjardine Creek eroded the palaeotributary sediments, exposing the groundwater table in the sediments. The subsequent discharge of groundwater would have accelerated erosion, and maintained the flow of groundwater as ground levels were lowered. This initial groundwater flow was probably brackish to saline. *Figure 8 (Appendix A)* shows a schematic cross-section highlighting the inferred mechanism.

7.1.1 Other Possible Mechanisms

It is stressed that the presence and continuity of the tributary has not been proven. It may in fact, extend to the north-east from the springs, along the inferred zone of fractured bedrock, and this is an intuitively more comfortable interpretation. However, review of local topographic contours (at 1:25,000 scale) indicates that the ground elevations in this area are high.

It is also possible that the groundwater is discharging through a fault system (fractured rock aquifer) similarly exposed by headward erosion of Cunjardine Creek, however this theory is discounted due to the low groundwater temperature and the relatively high discharge rates. Further, no fresh or weathered bedrock was observed at or near the springs.

The sandy nature of the sediments exposed in the northern flank of the springs (up to 4m thick) and the local continuity of low-lying land which connects the small wetlands in the area, supports the palaeodrainage interpretation.

7.2 AGE

The age of the springs cannot be determined with confidence without a reliable dating technique. Peat deposits may be suitable for radiocarbon dating, and selection of the deepest (which is probably the earliest) peat unit would be appropriate.

The sequence of geological events which shaped the development of the current landscape are known with reasonable accuracy. The palaeochannel systems were developed in the Tertiary. This places an earliest limit on the age of the springs of several million years. The development of a significant thickness of peat and intercalated sandy deposits would take at least several thousands of years.

The springs have been in existence for between several thousands of years to several millions of years. The evidence of active erosion indicates that they are probably no more then a few tens of thousands of years old.

7.3 GEOLOGICAL HISTORY SINCE DEVELOPMENT

Inception of the spring would have resulted in changing of the Cunjardine Creek from an ephemeral fresh-water system to a brackish to saline system with higher, fresher flows in wet seasons and lower, more saline flows in dry seasons (assuming climatic conditions similar to the present). The groundwater discharge would have been continuous, supporting development of a lush halophytic vegetation assemblage.

The investigation completed for this project indicates that a variable, shallow accumulation of inter-layered peat and sand occur. The peat materials formed as a result of accumulation of decomposed vegetation matter, and this is occurring today under the samphire, reeds and melaleucas which proliferate around the springs. Sand eroded from the northern flank, by discharge of groundwater, surface water runoff and biological disturbance, is the probable source of the sand layers.

Development of the peat restricted the rate of groundwater discharge due to its low permeability. The reduction of permeability would have driven the margins of the springs outward in a continuing process. The discharge would have moved to the edges of the peat, and as the travel distance required for groundwater to discharge at the edge of the peat increased, higher groundwater pressures beneath the peat induced groundwater discharge at weak points. Weak points in the peat (such as former tree-root holes) became discrete spring vents under the confined pressure. Recent anecdotal evidence and the author's observations indicate that the location and flows from the springs are in a state of constant flux. There are numerous locations within the spring complex where (inferred) remnant spring vents engulf unaware walkers. The vents comprise structurally weak strata, which were eroded by groundwater discharge, and have subsequently been obscured by vegetation.

A schematic local hydrogeological cross-section through the springs is provided in *Figure 8 (Appendix A)*.

Localised cementation of the sand and peat units was observed, and this probably occurred since development of the springs. The nature of the cement is not known, and is not considered to be significant.

7.4 HISTORICAL CHANGES IN HYDROGEOLOGY

Any long-term changes in the hydrogeology of the springs are not easily deduced. The spring flow rates have probably varied slightly as periods of enhanced erosion or peat accumulation resulted in fluctuations in groundwater discharge rates. As discussed above, the detailed hydrogeology is considered to be dynamic, with changes in vent locations, and groundwater discharge rates, over periods of months to tens of years.

There is a significant lack of recorded data for the springs, although it is noted that the surveyor Austen called Cunjardine Creek "Salt River" in 1858. The general flow and salinity have probably not changed significantly since.

Small areas of dead melaleucas indicate that there may have been some change in the water quality within the springs. The significance of the deaths is unknown, as there are numerous examples of apparently healthy melaleucas and other vegetation living within spring discharge areas. It is possible that fire or pest/animal damage killed the trees.

7.5 RELATIVE CONTRIBUTIONS FROM THE AQUIFERS

The majority of the water driving the springs comes from the palaeotributary aquifer. Based on the geological model of the site (that is, a palaeotributary which is incised into the granitic weathering profile), the sand-plain aquifer is probably not present in the immediate vicinity of the springs. Any surficial sand deposits have probably been reworked by wind action, and formed in a similar fashion to the sand-plain aquifer in the region. However, as the reworked sand and silt is probably in good hydraulic connection with the underlying palaeotributary aquifer, it is likely either unsaturated or simply forms part of a combined aquifer system. It is possible that the upper portion of the palaeotributary aquifer contains lower salinity groundwater due to rainfall recharge, and this would not contradict the limited field data that are available.

It is possible that there are fringing plant species, on the elevated northern flank of the springs, that receive or are reliant on either a continuous or seasonal flow of lower salinity water. Thus reductions in the local groundwater recharge (which may occur if the land surface adjacent is heavily replanted) may have a limited impact on part of the ecosystem, although this is speculative.

7.6 LIKELY FUTURE CHANGES

The vast groundwater reserves within the palaeochannel system indicate that the discharge of groundwater from the springs has probably not significantly altered the water quality or pressure in the palaeochannel aquifer. Establishment of a monitoring network for the springs is recommended to obtain reliable data from which more rigorous interpretations can be made.

7.7 GROWTH OF THE SPRINGS

The current area of the springs (which defines the area of the ecosystem which depends on the groundwater discharge), has grown over time to its current size. It is not known if the springs are still growing, are stable, or change with seasonal or longer scale changes in the groundwater system.

There is likely to be a steady-state condition where the total volume of groundwater discharge through the springs area is in equilibrium with the aquifer. If aquifer pressures rise (due to increased recharge, perhaps) or if the permeability of the peat confining layers is reduced by continued vegetation growth and build up of decaying matter, then the area of the springs would increase. Likewise, reduction in aquifer pressure or release of additional water (perhaps by careless investigation drilling through the peat), would cause the area of the springs to decrease. It is likely that any natural changes to the size of the springs would be very slow and would be on the scale of decades rather than in response to short seasonal variations.

The presence of slightly salinised soils at the margins of the springs indicates that groundwater discharge is not high enough to flush salt from the soil, and the elevated soil salinity probably restricts expansion of the spring vegetation complex.

It is thought that the area of the springs is probably stable given the apparent long history of groundwater discharge, although there is no real evidence for this.

7.8 THREATS

Threats to a groundwater-supported system comprise either threats to the quality or quantity of groundwater.

7.8.1 Quality

Groundwater quality may be impacted by land-use (leachate of pesticides, herbicides or fertilisers) in the groundwater catchment. As the palaeochannel aquifer is thought to be recharged in the Lake Dowerin region, land-use in the district is unlikely to impact on the springs due to the large distance. Further, natural processes usually serve to degrade and mix contaminants along the groundwater flow path, and occurrence of common groundwater contaminants, in detectable concentrations, more than 1km from the source is rare.

There is potential for discharge of shallow groundwater at the flank of the springs. If the shallow groundwater became contaminated, then detectable concentrations of contaminants may occur in localised areas of the springs. Management of the land area within approximately 500m around the margins of the springs would be sufficient to negate these risks. Such a buffer already exists and the arable land within the region is being replanted by the land owners.

7.8.2 Quantity

Significant lowering of groundwater levels in the Lake Dowerin palaeochannel may reduce spring flows. Such lowering would occur in the event of large scale groundwater use or interception of recharge by vegetation.

Groundwater use is unlikely to be an issue as the palaeochannels contain brackish to saline groundwater, which has limited value,

It is similarly felt unlikely that replanting projects in the region would have a significant short-term effect on palaeochannel groundwater pressures. Should pressures be lowered in the long term (50-100 years), then it is felt likely that any reductions in spring discharge will be accompanied by gradual changes in the springs community, and efforts to buffer against such a change would be misguided.

The magnitude of the system which supports the springs provides a significant buffer against short-term changes.

8. MANAGEMENT IMPLICATIONS

The regional source of the spring discharge water means that local land or water management would have little impact on the springs. The springs are considered to be a dynamic but robust groundwater discharge feature which is likely to continue to function as it functions today. Long term changes due to land revegetation, if they occur, may result in slow change to the springs.

Local changes in groundwater level and/or salinity are unlikely to have significant implications on the spring environment.

The issues to address in ongoing management of the springs are:

- Land-use within about 500m of the springs (potential for contamination of the shallow aquifer);
- Isolation from stock and other grazing animals; and
- Revegetation in the Lake Dowerin palaeochannel catchment (likely small to negligible reduction in flows over extremely long time).

9. RECOMMENDATIONS

Further hydrogeological investigations, if considered, should be focussed towards the following objectives:

- Confirmation of the presence of a palaeochannel aquifer;
- Establishment of a reliable network of monitoring piezometers;
- Testing the aquifer continuity, groundwater chemistry and hydraulic gradient along the inferred pathway between the palaeochannel and the springs;
- Implementation of a monitoring programme for the groundwater system that supports the springs;
- Establishment of formal groundwater quality and flow monitoring locations within the springs;
- Implementation of a monitoring programme for the surface water system that discharges from the springs; and
- Vegetation and invertebrate monitoring as deemed appropriate by CALM.

It is the author's opinion that investigation and monitoring of the system which supports the springs, although academically stimulating, is unlikely to have any direct bearing on the management of the springs.

9.1 GROUNDWATER MONITORING

A provisional design for a suitable groundwater monitoring network is shown below. The network assumes that:

- comprehensive investigations are not required;
- installation of groundwater monitoring piezometers within the springs is considered a relatively high risk and is to be avoided at this stage;
- monitoring wells would be installed using a small rig (which allows greater depths to be achieved than by hand installation).

9.2 INITIAL STAGE – GROUNDWATER MONITORING PIEZOMETERS

- Drill two investigation holes, to nominally 10-15m depth, on the elevated land at the northern margin of the springs, to assess the lithological profile and to test the palaeotributary hypothesis;

- Construct nominally four to six piezometers at various locations on the northern side of the springs (piezometer locations and depth setting would need to be determined on the basis of the results of the test holes),

- Set the screens in the piezometers at depths as dictated by the aquifer hydrogeology, perhaps two just below the water table, and two at greater depth.

- Collect water samples for comprehensive chemical analysis and comparison with the type of groundwater which is discharged from the springs.

The location for the first hole would be at the nearest accessible point to the normal access track to the springs. The location for the second hole would be between 50 and 100m to the east, also near to the break of slope.

It is important to recognize that the value of groundwater monitoring data depends on the siting and construction of suitable piezometers. This in turn relies on sufficient understanding of the hydrogeology of the site. Installation of the piezometers as outlined above would provide additional information on the hydrogeology of the site, and it is hoped that the piezometers would be suitable for long term monitoring.

On behalf of Groundwater Consulting Services Pty Ltd,

SAM BURTON
MANAGING DIRECTOR.

10. LIMITATIONS

Groundwater Consulting Services Pty Ltd has prepared this report for the Department of Conservation and Land Management in accordance with generally accepted groundwater consulting practice. The specific conditions of the contract and subsequent communications, including express or implied limitations on the scope of work or the budget, have had a bearing on the scope and detail of the project, and on the level of confidence in the findings.

Groundwater Consulting Services' 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 land-use that may not be known or predictable. Conservative assumptions were used where-ever possible, however, estimates of bore and aquifer yield or predicted impacts of pumping can be inaccurate, especially when the conditions on which predictions were made have changed. Groundwater Consulting Services Pty Ltd's predictions are made on the basis that the client will contract Groundwater Consulting Services Pty Ltd to undertake regular reviews of operational data, and such reviews may lead to groundwater availability, quality or other predictions being re-estimated.

Groundwater Consulting Services Pty Ltd does not provide advice on water requirements, irrigation schedules, irrigation system design and other non-groundwater related areas. Groundwater Consulting Services Pty Ltd's advice on bore location, construction, operation or other factors must be considered by the client, after the client has obtained expert advice from other relevant disciplines.

This report must not be used by other parties without the prior express written consent of Groundwater Consulting Services Pty Ltd, with the exception of regulatory authorities. If this report is provided to third parties for reliance, then the client assumes all liability for the representations made in the report.

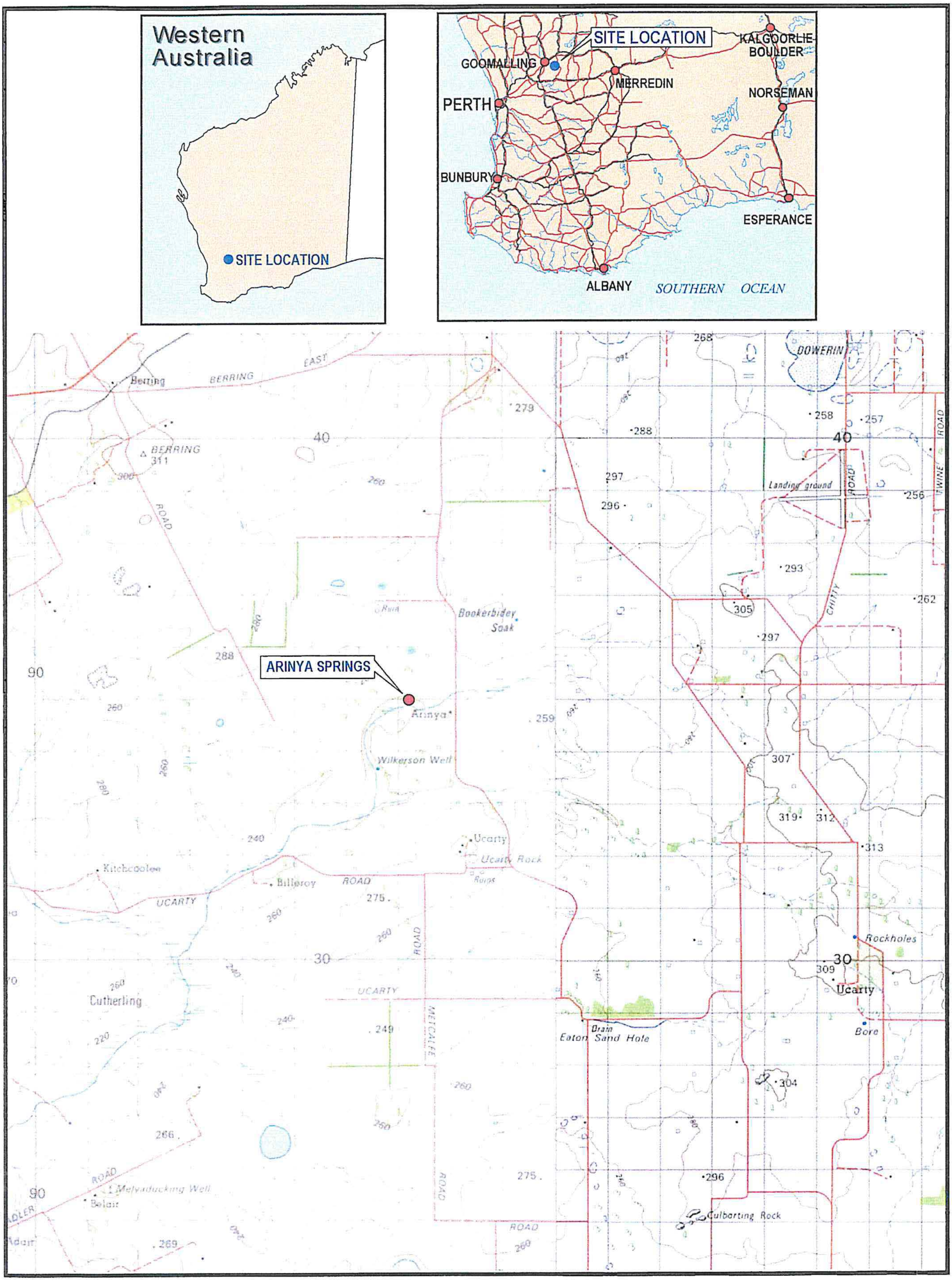
11. APPENDICES

Appendix A – Figures

Appendix B – Laboratory Analytical Report

Appendix A

Figures

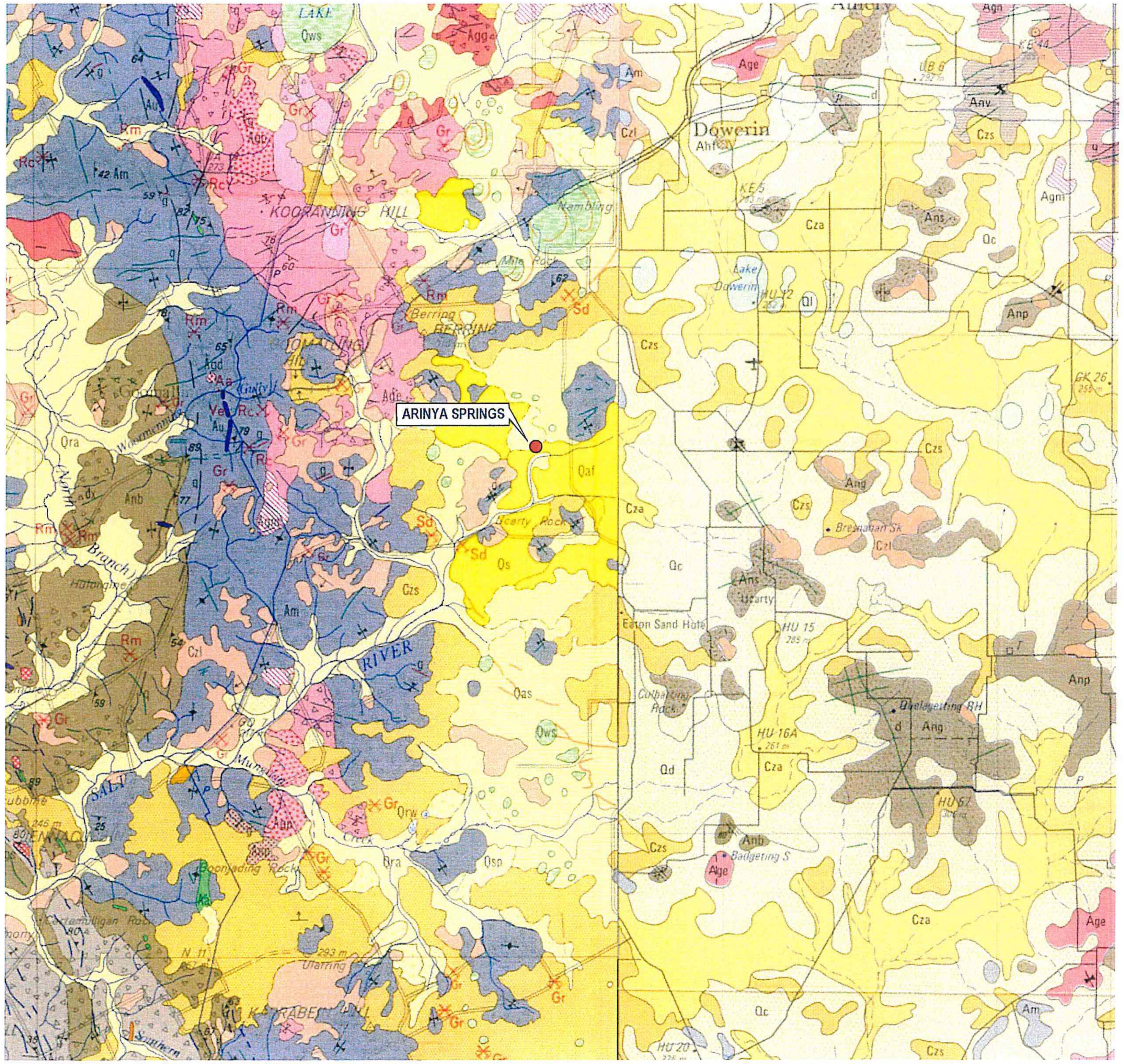


GCS/CALM007/Figure 1/January 2003.fh8

GCS Groundwater Consulting Services Pty Ltd

Figure 1:	*SITE LOCATION*
Location:	*Goomalling*
Drawing Date:	*January 2003*
Projection:	*AMG*
Client:	*CALM*
File Name:	*CALM007*

0 2000m



REFERENCE

Qrw	Swamp and lacustrine deposits—peat, peaty sand and clay
Qra	Alluvium—clay, sand and loam
Qws	Salt lake deposits—saline silt and clay
Qrg	Estuarine, lagoonal and lacustrine deposits—clay, silt, marl with shell beds
Qro	Shell beds of Rottnest Island—fossiliferous limestone and unlithified shell beds
Qrs	**SAFETY BAY SAND:** eolian and beach lime sand, slightly lithified
Qrsm	calcareous quartzose sand (mobile dunes)

Qrc	Colluvium, including valley-fill deposits, variably lateritized and podsolized
Qa	Alluvium and minor colluvium developed on laterite of the Darling Range
Qaf	Older sandy alluvium in eastern part of Sheet, dissected by present drainage
Qas	Sand—variously reworked, associated with older stream channels
Qs	Sand—bright yellow, hummocky deposits marginal to stream channels
Qsp	Thin veneer of sand, with bands of ferruginous pisoliths, overlying Archaean granitic rocks
Qm	Sandy colluvium from Cretaceous rocks, variably lateritized
Qpo	Colluvium, soil and undifferentiated sand over laterite of Coastal Plain Includes minor alluviated areas

Age	Even-grained granitic rocks—fine to coarse-grained granodiorite, adamellite and granite
Agp	Porphyritic granite—medium to coarse-grained granite with microcline megacrysts
Agv	Fine to medium-grained adamellite and granite with scattered microcline megacrysts
Agg	Leucocratic adamellite, fine to medium-grained with abundant pegmatite
Agm	Mixed granitic rocks, chiefly interdeveloped even-grained and porphyritic granite
Agn	Gneissic granite, with cataclastic foliation

Au — Ultramafic dykes and sills—peridotite and pyroxenite, often foliated and variously altered to greenschist facies metamorphic assemblages

Ags	Syenitic rocks, range from monzosyenite to syenite
Agd	Dioritic rocks, range from monzonite to diorite

Am	Migmatite—banded and nebulitic, often strongly contorted
Amh	amphibole-bearing migmatite, rich in amphibolite lenses and blocks

Anp	Porphyritic granite gneiss, coarse-grained with abundant tabular megacrysts of microcline
Ana	Augen gneiss, coarse-grained with microcline augen, strong cataclastic foliation
Anb	Quartz-feldspar-biotite gneiss, generally well-banded, may contain garnet
Anl	Quartz-feldspar (-garnet-biotite) gneiss, leucocratic, often with elongate felsic areas
Anf	Quartz-feldspar-biotite granofels, melanocratic and poorly banded
Anc	Interbanded quartz-hornblende-biotite-garnet gneiss, quartz-feldspar gneiss and amphibolite, some mylonite zones
And	Quartz-feldspar-hornblende-biotite gneiss and schist

Alb	Quartz-mica schist, biotite generally in excess of muscovite
Als	sillimanite-bearing schist
Alk	kyanite-bearing schist
Ala	andalusite-bearing schist
Aln	staurolite-bearing schist
Alg	Quartz-mica-garnet schist
Alm	Muscovite-chlorite phyllitic schist

GCS/CALM007/Figure 2/January 2003.fh8

GCS Groundwater Consulting Services Pty Ltd

Figure 2:	*REGIONAL GEOLOGY*
Location:	*Goomalling*
Drawing Date:	*January 2003*
Projection:	*AMG*
Client:	*CALM*
File Name:	*CALM007*

0 5000m

GCS/CALM007/Figure 3/January 2003.fh8

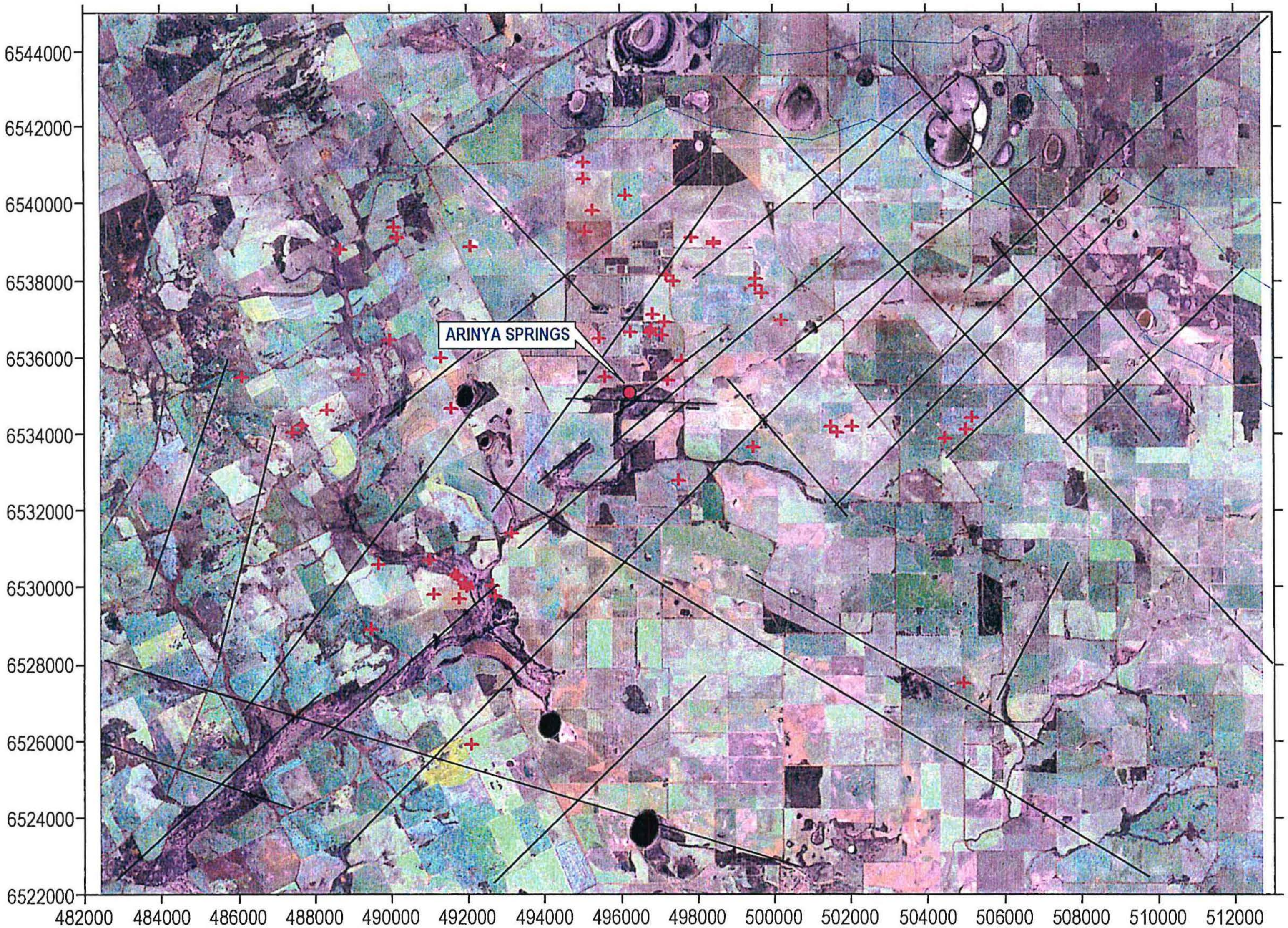
GCS Groundwater Consulting Services Pty Ltd

1-6 Location of Water Quality / Flow Measurement - Source
2-6 Location of Water Quality / Flow Measurement - Composite
48900 EC
7.83 PH
26.4 Temperature

Figure 3:	*FIELD WATER CHEMISTRY*
Location:	*Goomalling*
Drawing Date:	*January 2003*
Client:	*CALM*
File Name:	*CALM007*

0 50m

Arinyah Springs - Regional Satellite Data, Bore Locations and General Structural Interpretation



GCS/CALM007/Figure 8/January 2003.fh8

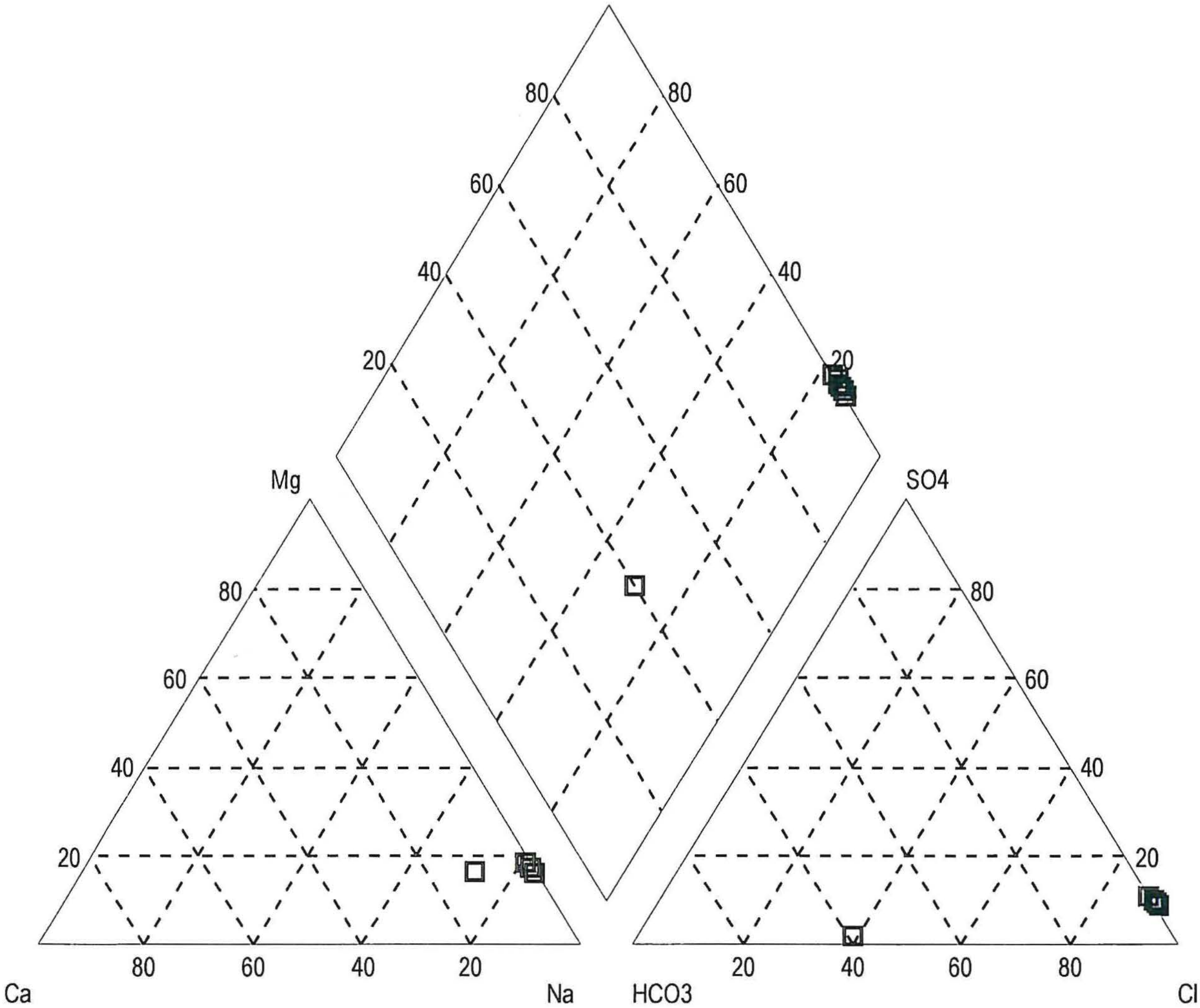
Groundwater Consulting Services Pty Ltd

Figure 4: *SATELLITE IMAGE & INFERRED GEOLOGICAL STRUCTURES*

Location:	*Goomalling*
Drawing Date:	*January 2003*
Client:	*CALM*
File Name:	*CALM007*

0 4000m

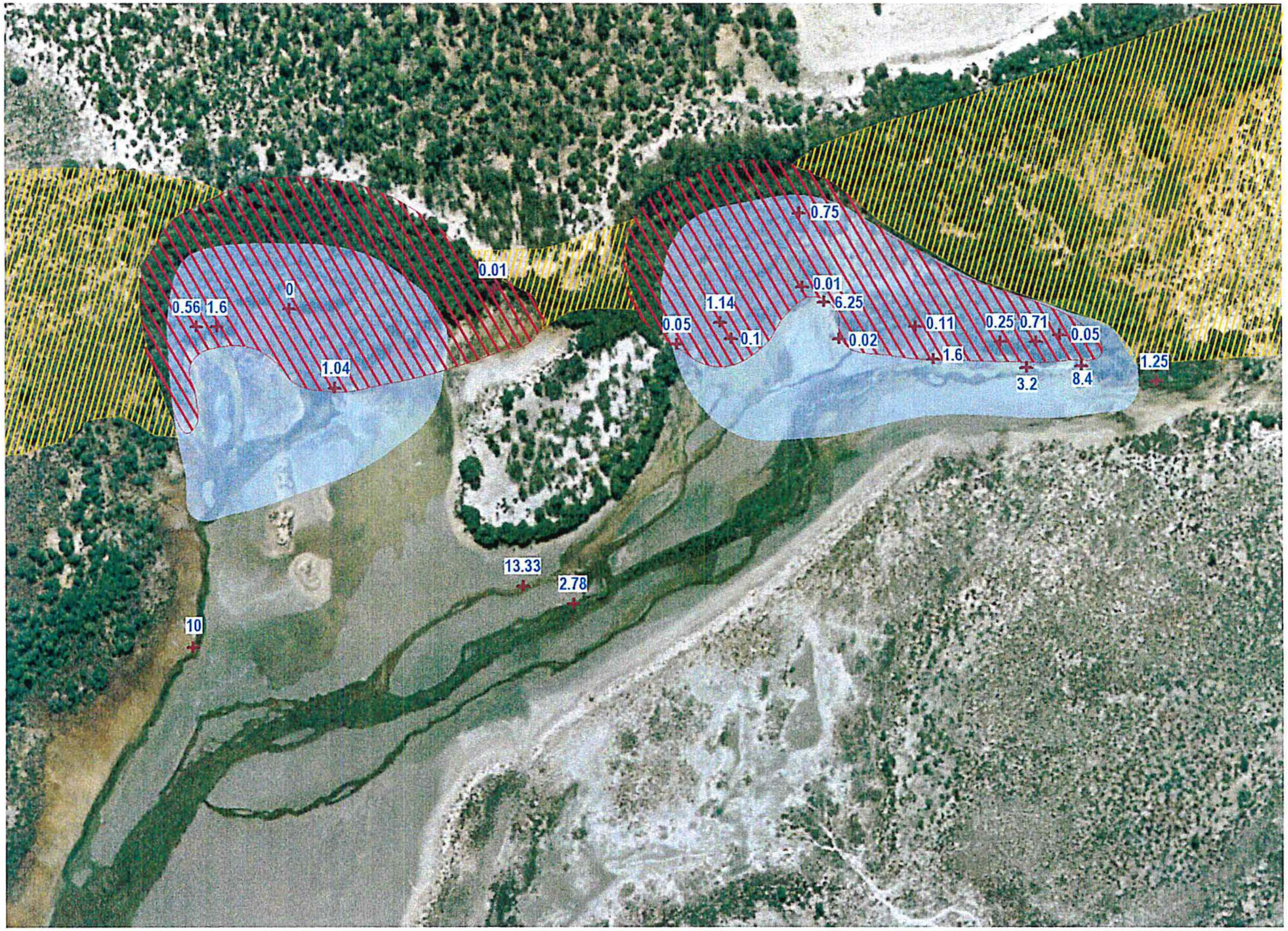
Dowerin Springs - Groundwater Typing



GCS/CALM007/Figure 9/January 2003/hh8

GCS Groundwater Consulting Services Pty Ltd

Figure 5:	*PIPER TRILINEAR DIAGRAM GROUNDWATER CHEMICAL TYPING*
Location:	*Goomalling*
Drawing Date:	*January 2003*
Client:	*CALM*
File Name:	*CALM007*



GCS/CALM007/Figure 4/January 2003.fh8

GCS Groundwater Consulting Services Pty Ltd

Extent of Surface / Subsurface Peat

Extent of Free Groundwater Discharge

Extent of Evaporative Groundwater Discharge

13.33 Estimated Flow Rate

Figure 6: *FIELD GEOLOGICAL MAPPING*

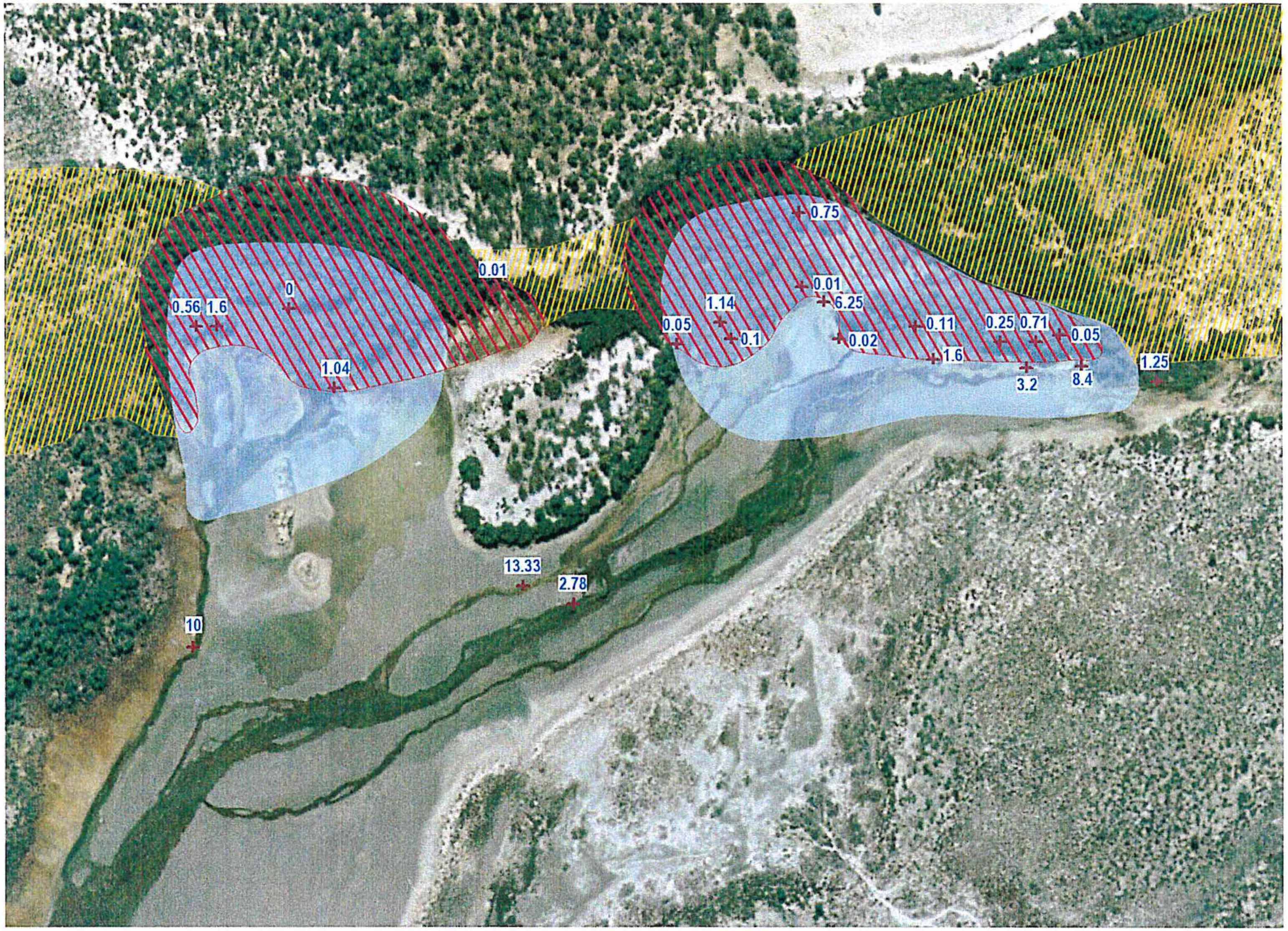
Location: *Goomalling*

Drawing Date: *January 2003*

Client: *CALM*

File Name: *CALM007*

0 50m



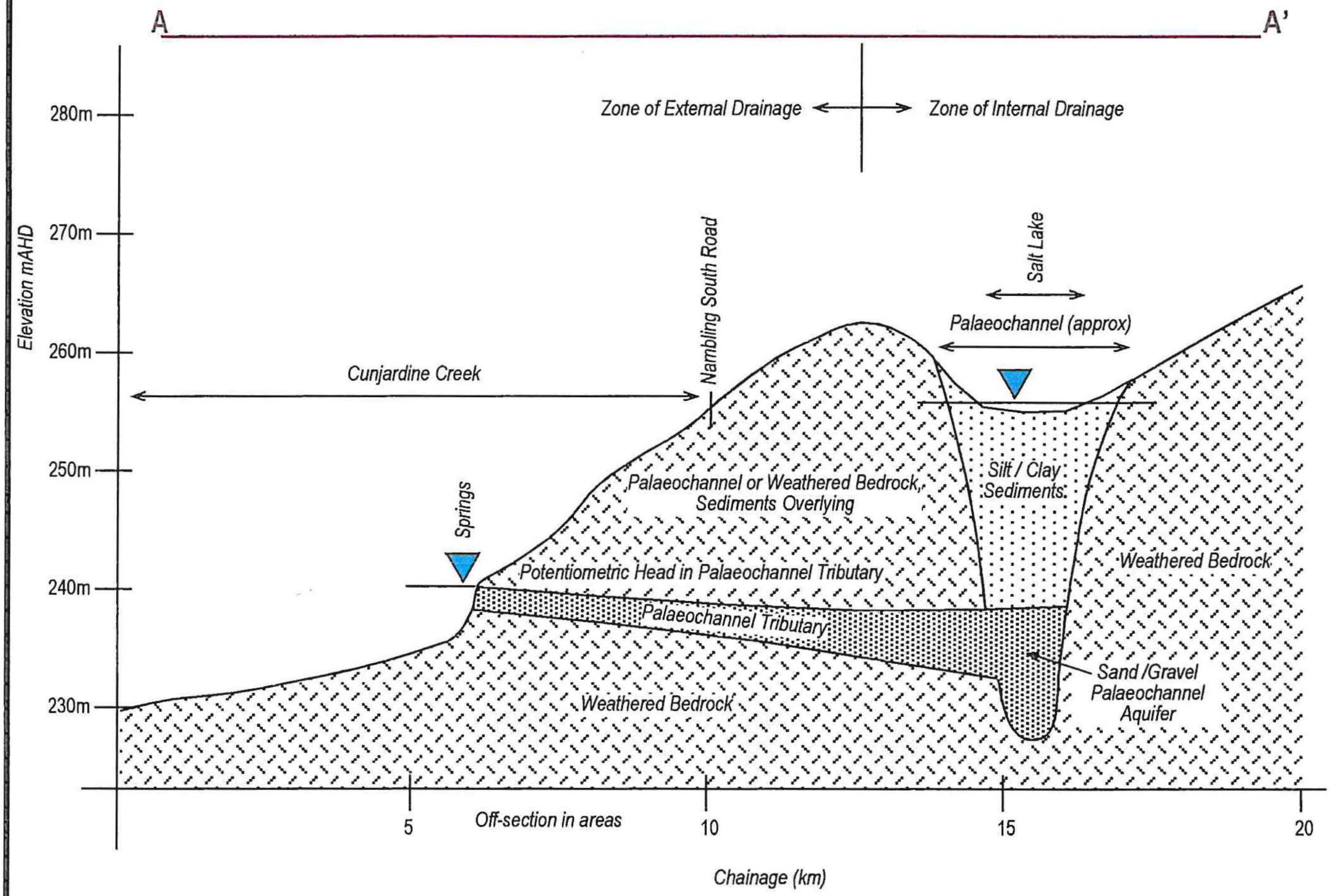
GCS/CALM007/Figure 4/January 2003.fh8

GCS Groundwater Consulting Services Pty Ltd

(blank box)	Extent of Surface / Subsurface Peat
(red hatching)	Extent of Free Groundwater Discharge
(yellow hatching)	Extent of Evaporative Groundwater Discharge
13.33	Estimated Flow Rate

Figure 6:	*FIELD GEOLOGICAL MAPPING*
Location:	*Goomalling*
Drawing Date:	*January 2003*
Client:	*CALM*
File Name:	*CALM007*

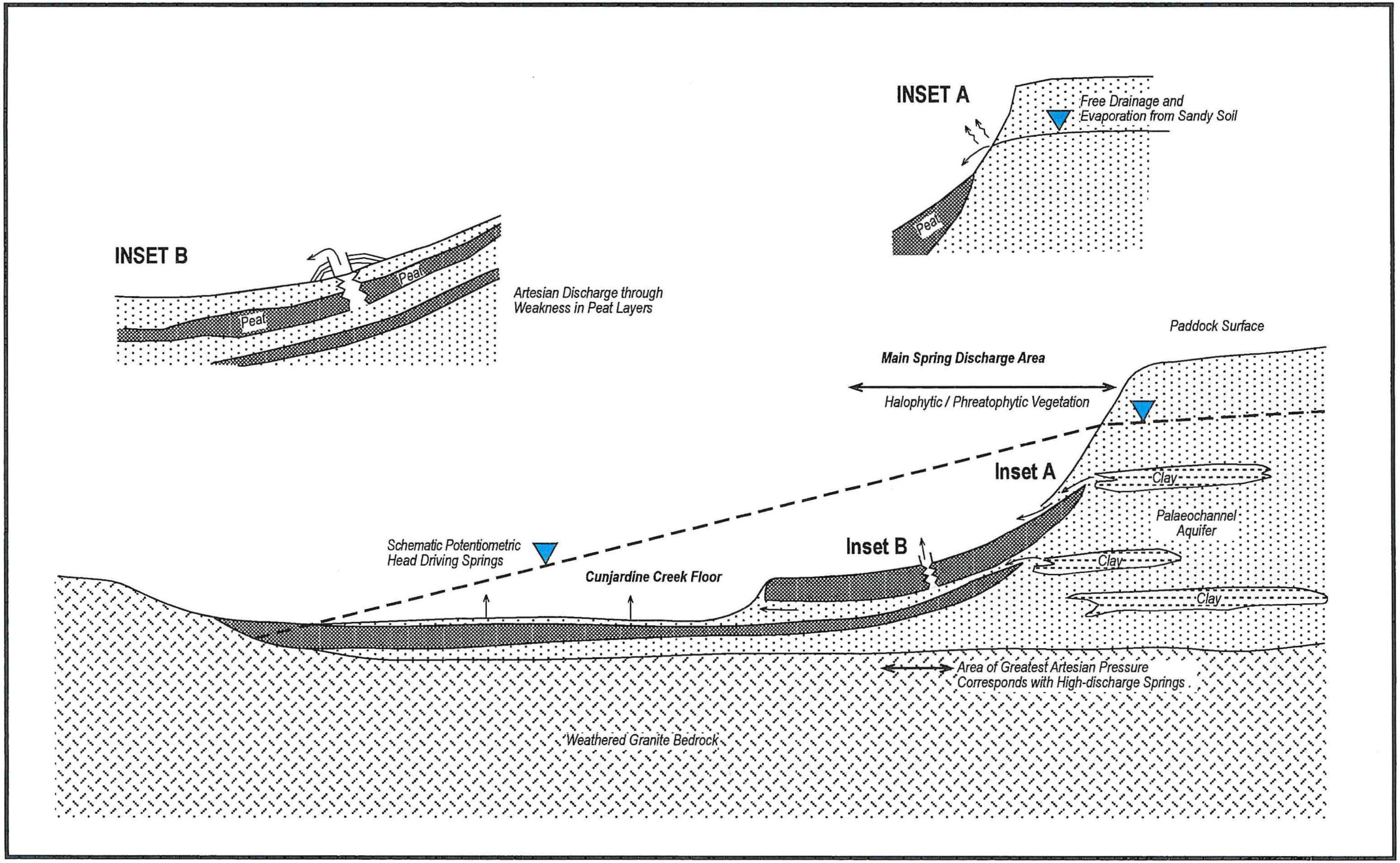
0 2000m



GCS/CALM007/Figure6/January 2003.fh8

GCS Groundwater Consulting Services Pty Ltd

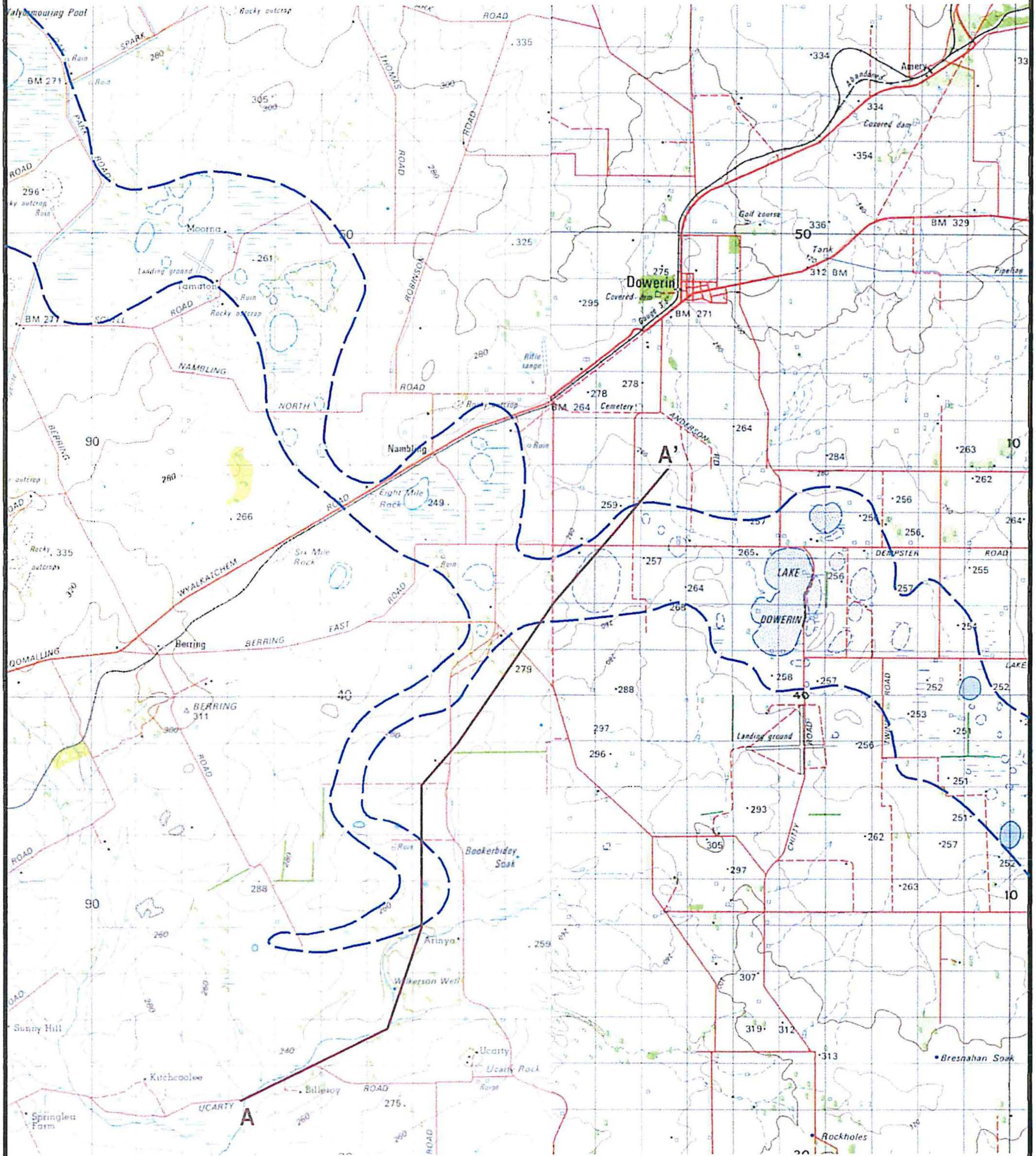
Figure 7:	REGIONAL HYDROGEOLOGICAL CROSS-SECTION
Location:	Goomalling
Drawing Date:	January 2003
Client:	CALM
File Name:	CALM007



GCS/CALM007/Figure7/January 2003.hb8

GCS Groundwater Consulting Services Pty Ltd

Figure 8:	*LOCAL HYDROGEOLOGICAL CROSS-SECTION*
Location:	*Goomalling*
Drawing Date:	*January 2003*
Client:	*CALM*
File Name:	*CALM007*



GCS Groundwater Consulting Services Pty Ltd

Figure 9:	*INFERRED PALAEOCHANNEL LOCATION*
Location:	*Goomalling*
Drawing Date:	*January 2003*
Projection:	*AMG*
Client:	*CALM*
File Name:	*CALM007*

0 2000m

Appendix B

Laboratory Analytical Report

SGS

LABORATORY REPORT COVERSHEET

DATE: 22 January 2003

TO: Groundwater Consulting Services Pty Ltd

12 Scenic Drive

WANNEROO WA 6065

ATTENTION: Mr Sam Burton

YOUR REFERENCE: Water Analysis (CALM)

OUR REFERENCE: 69592

SAMPLES RECEIVED: 09/01/03

SAMPLES/QUANTITY: 13 Waters

The above samples were received intact and analysed according to your written instructions. Unless otherwise stated, solid samples are reported on a dry weight basis and liquid samples as received.

JANICE VENNING
Manager, Perth

PETER BAMFORD
Manager Laboratory Services

This report supersedes our preliminary results that were reported by facsimile.
This report must not be reproduced except in full.

Analabs Pty Ltd
ABN 91 004 591 664
Environmental Services 52 Murray Road, Welshpool 6106 Western Australia www.sgs.com
t +61 (0)8 9458 7278 f +61 (0)8 9451 3505

SGS

CLIENT: Groundwater Consulting Services Pty Ltd **OUR REFERENCE:** 69592
PROJECT: Water Analysis (CALM)

LABORATORY REPORT

Your Reference Our Reference Type of Sample	Units	New Soak 69592-2 Water	1-3 69592-5 Water	1-6 69592-6 Water	1-10 69592-7 Water	2-3 69592-10 Water
pH	pH Units	8.0	6.4	6.7	6.6	6.8
Electrical Conductivity @ 25°C	µS/cm	1100	50000	87000	33000	35000
Total Dissolved Solids (grav) @ 180°C	mg/L	760	29000	49000	19000	21000
Sodium, Na	mg/L	190	9200	16000	6000	6600
Potassium, K	mg/L	28	160	290	130	140
Calcium, Ca	mg/L	28	190	310	100	100
Magnesium, Mg	mg/L	22	970	1700	540	570
Chloride, Cl	mg/L	170	18000	29000	11000	12000
Carbonate, CO_3	mg/L	<1	<1	<1	<1	<1
Bicarbonate, HCO_3	mg/L	450	65	95	65	65
Sulphate, SO_4	mg/L	11	2200	3600	1200	1200
Nitrate, NO_3	mg/L	0.2	7.2	3.7	18	13
Cation/Anion balance	%	-0.33	-5.18	-1.77	-5.28	-3.73
Sum of Ions (calc.)	mg/L	893	30537	50819	19473	20850

SGS

CLIENT: Groundwater Consulting Services Pty Ltd **OUR REFERENCE:** 69592
PROJECT: Water Analysis (CALM)

LABORATORY REPORT

Your Reference Our Reference Type of Sample	Units	2-7 69592-12 Water	1-13 69592-13 Water
pH	pH Units	7.6	6.2
Electrical Conductivity @ 25°C	µS/cm	69000	20000
Total Dissolved Solids (grav) @ 180°C	mg/L	38000	12000
Sodium, Na	mg/L	12000	3800
Potassium, K	mg/L	220	90
Calcium, Ca	mg/L	220	56
Magnesium, Mg	mg/L	1200	320
Chloride, Cl	mg/L	23000	7200
Carbonate, CO_3	mg/L	<1	<1
Bicarbonate, HCO_3	mg/L	60	50
Sulphate, SO_4	mg/L	2600	660
Nitrate, NO_3	mg/L	6.7	23
Cation/Anion balance	%	-4.97	-5.15
Sum of Ions (calc.)	mg/L	39309	12201

SGS

CLIENT: Groundwater Consulting Services Pty Ltd **OUR REFERENCE:** 69592
PROJECT: Water Analysis (CALM)

LABORATORY REPORT

TEST PARAMETERS	UNITS	LOR	METHOD
Standard 1			
pH	pH Units	0.1	PEI-001
Electrical Conductivity @ 25ºC	µS/cm	1	PEI-032
Total Dissolved Solids (grav) @ 180ºC	mg/L	10	PEI-002
Sodium, Na	mg/L	0.5	PEM-001
Potassium, K	mg/L	0.5	PEM-001
Calcium, Ca	mg/L	0.5	PEM-002
Magnesium, Mg	mg/L	0.5	PEM-002
Chloride, Cl	mg/L	1	PEI-020
Carbonate, CO_3	mg/L	1	PEI-006
Bicarbonate, HCO_3	mg/L	5	PEI-006
Sulphate, SO_4	mg/L	1	PEI-020
Nitrate, NO_3	mg/L	0.2	PEI-020
Cation/Anion balance	%		Calc.
Sum of Ions (calc.)	mg/L		Calc.

NOTES:
LOR - Limit of Reporting.

FAXED

GCS Groundwater Consulting Services Pty Ltd

12 Scenic Drive
Wanneroo 6065
Western Australia

Telephone: 61 8 9405-8463
Facsimilie: 61 8 9405-8462

9 December 2002

Rick Staker
Australian Environmental Laboratories
52 Murray Rd
WELSHPOOL WA

Dear Sir,

SUBJECT: Water Analysis (CALM)

A total of thirteen water samples were delivered to AEL on 9 Decmeber 2003. Please analyse samples identified by "New Soak", "1-3", "1-10", "1-12", "1-13", "2-3" and "2-7" (total seven samples) for the following:

- pH, EC and TDS (gravimetric)
- Na, K, Ca, Mg, Cl, SO4, NO3, CO3, HCO3

Do not hesitate to call if you have any queries.

Yours faithfully
GROUNDWATER CONSULTING SERVICES PTY LTD

Sam Burton
Managing Director.

Australian Environmental Laboratories
Received 9/1/03
Time .... am. Samples
By Natalie
Ice/Cooler Pack yes.
Samples intact yes.
Comments:
69592