Lake Bryde Recovery Catchment

Hydrogeology of Lake Bryde

Rev 1

December 2000

A report prepared for the Department of Conservation and Land Management

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1. Executive Summary

Sinclair Knight Merz has completed hydrogeological investigations for the Lake Bryde catchment for the purpose of establishing the potential impacts from salinity, particularly to the lakes and nature reserves in the valley floors.

- Groundwater risk mapping and modelling indicates that groundwaters are rising and will impact upon the majority of lake and wetland systems in the lower landscape within the next 5-10 years. Vegetation and ecological communities below the 300mAHD contour will be impacted.

- At present salinity degradation is resulting from the discharge of saline enriched surface waters running from the surrounding catchment, discharging into fresh to brackish lakes.

Rising Groundwater Trends
Groundwater is rising from increased recharge. Groundwater occurs and flows within basement granites and associated weathering profile (saprolite), Tertiary sands and clays at the base of the palaeochannel deposits and clay and sand mixtures representing Quaternary sediments within low lying areas and valley floors.

- Groundwater hydrographs indicate that saline groundwater levels are rising, bringing salts towards the surface.

Groundwater recharges via direct rainfall infiltration and leakage from underlying and overlying units. Groundwater is shown to be flowing towards the lower catchment along gentle gradients.

- Low aquifer transmissivities and throughflow volumes ensures that the available storage capacity of the aquifer is reduced and groundwater levels will rise.

It is considered that there is some hydraulic connection between aquifers.

Predictive Salinity Risks and Management
A number of predictive and treatment scenarios were modelled to represent changes to the catchment water balance and groundwater level responses. The results must be viewed in context of model limitations.

- The water table is likely to rise relatively uniformly through the lower catchment and the spatial impact will to some degree depend upon the elevation of the land surface and base of the lakes. Some variations may occur due to localised confined conditions. The water table will rise and discharge into the lakes as base discharge.

- The modelling results indicated that recharge reduction will not prevent elevated piezometric pressures in the lower catchment and groundwater levels close to the surface, resulting in the degradation of natural resources within the next 5 to 10 years even when this recharge reduction was equivalent to total revegetation of the catchment.

- Simulation of recharge reduction equivalent to partial revegetation had little effect on reducing piezometric pressures and water levels within the lower catchment.

- Long term recharge reduction via an integrated system of revegetation and surface water drainage, may result in a reduction in groundwater recharge and potentially a reduction in piezometric pressures and water levels. However, the effects of recharge reduction will not occur quickly enough to prevent the deterioration of the lower catchment and lakes.

Groundwater pumping from the Tertiary and Quaternary deposits was simulated within the lower catchment.

- Results indicate that water levels could be reduced locally and to some degree regionally from low volume groundwater pumping (9L/s in total) from three bores located around Lake Bryde.

Besides groundwater pumping, another option includes drainage of shallow groundwater and surface water diversion to reduce the salt load to lakes and reduce recharge within the waterlogged areas. These options were not modelled due to model and contractual limitations.

- Any engineering management option would need to be integrated with revegetation of recharge areas and the use of perennial pastures and high water use crops.

Recommendations

A combination of integrated management options is required. It is apparent that to avoid complete degradation, specific lakes, wetlands and land areas need to be identified for protection, while other areas will be sacrificed. Areas of greater environmental value need to be identified and protective measures individually assessed.

- Water disposal issues and options need to be explored further if any of these remedial techniques are to be considered.

Management options will need to be considered in context of the entire catchment and integrated with any other catchment management plan.

- A hydrology study is recommended to define the surface water flow regime within the “entire catchment”.

- Additional groundwater piezometers are required within the catchment to enable further development of a conceptual hydrogeological model, monitor specific aquifers and define groundwater pumping options.

2. Introduction

2.1 Purpose of the Assessment

A hydrogeological study has been completed within the Lake Bryde catchment for the purpose of establishing the conceptual hydrogeological regime and identifying the sensitivity of the system to changes in the catchment water balance, and ultimately salinisation. The study also considers salinity risks and mitigation options to the lake reserves and surrounding catchment.

The bulk of the study was based upon previous investigations and available information.

The Lake Bryde Wetland Complex is important due to its unique biological and physical diversity and has been nominated as a recovery catchment for natural diversity under the State Salinity Strategy 2000.

Clearing of the catchment for agriculture has resulted in significant changes to the water balance resulting in an observed rise in groundwater and an increase in surface and groundwater salinity. Salinity induced by clearing is impacting upon the lower catchment drainage flats and some freshwater lakes, threatening ecological communities and land production.

2.2 Aim of the Hydrogeological Assessment

The primary aim of the study was to complete an assessment of the hydrogeological regime to identify dominant salinity risks and threatening processes affecting the health of lakes within the catchment. This was achieved by:

- Developing a conceptual hydrogeological flow model, compiled from existing information, identifying areas of significant groundwater recharge and geological, geomorphological and landuse controls on groundwater flow dynamics.

- Identifying gaps in hydrogeological information and the need for further investigations and monitoring.

- Defining the application and suitability of airborne geophysical techniques to the catchment for salinity management purposes.

- Modelling groundwater salinity risk areas and hydrogeological response to various management scenarios, such as recharge reduction and groundwater pumping.

2.3 Work Scope

The assessment included the following:

- Compilation and review of existing bore logs, water chemistry, water level hydrographs, aerial photographs, hydrogeological and hydrological reports, groundwater data base information, climatic data and identification of gaps in data.

- Collection, analysis and interpretation of field data including permeability testing and groundwater and surface water sampling.

- Development of a conceptual groundwater flow model, identifying aquifer characteristics, mechanisms of recharge and flow, surface water interaction and processes of salinisation.

- Catchment groundwater modelling to predict water level changes under various hydrological scenarios, including recharge reduction and the addition of management options.

- Description of the dominant threatening processes to the ecological sustainability of the two major lakes, Lake Bryde and East Lake Bryde, and temporal and spatial impacts from groundwater.

3. Background

3.1 Study Area

The study area is 25 km south east from Lake Grace, 38 km east from Pingrup and 37 km south west of Newdegate. Physiographically, the Lake Bryde catchment area is located between Lake Grace and Lake Lockhart and comprises of a series of northerly draining freshwater and naturally saline lakes. The lake chain is at the headwaters of the Lockhart sub-catchment of the Swan Avon system where drainage has been depositing sediments since potentially the late Cretaceous. The catchment is an internally drained system and comprises of approximately 6 sub-catchments.

The primary catchment study area covers approximately 140,400 ha from the upper catchment to Mallee Hill Road. Approximately 64% of the catchment has been cleared for agriculture. Clearing dominantly occurred within the 1960s and 1970s. Recent clearing has occurred to the west of the Lake Bryde wetland system. The primary landuse is cereal pasture rotation with some annual legume crops grown. **Figures 3.1, 3.2 and 3.3** illustrates the Lake Bryde catchment study area.

Remnant vegetation exists to the south east of the catchment within the Lake Magenta Nature Reserve. Large areas of vegetation also exist within the lower catchment, exclusively within Lakeland and Lake Bryde Nature Reserves.

Lake Bryde has previously been used as a drought relief water supply. Alternative water supplies and an increase in salinity has resulted in limited reliance now on the lake. Photos of the catchment are shown in **Appendix F**.

Figure 3.2: Aerial view draped over topography of Lake Bryde catchment

Figure 3.3: Lake Bryde Reserve

3.2 Salinity Issues Affecting Catchment

Secondary soil and water salinity has been identified within the catchment. Anecdotal records indicate that salinity became visible within the early 1990s. However, it is likely that isolated areas of salinity existed soon after clearing.

There are numerous landuse, hydrological and geological factors influencing salinity within the study area including waterlogging, inundation, shallow groundwater and saline enrichment of surface water. As a result of clearing, the catchment water balance has been altered, resulting in a greater volume of surface water runoff, increased groundwater recharge and salt accumulation.

Within the lower catchment salinity is currently associated with surface water inundation and secondary enrichment. Surface water runoff from cleared land is enriched in secondary salinity, and discharges into lakes and stagnant flats within the lower catchment.

Geological features such as dykes, faults and changes in soil types have also contributed to salinity. As the majority of clearing has occurred within the last 30 years, it is likely that land and water salinity and deterioration of the lake and wetland complex will continue.

At present the deterioration of the lake and surrounding landscape is typically resulting from saline surface water discharge. Overheu (1999) indicated the primary cause of Lake Bryde's deteriorating condition is the later season low volumes of surface water draining over or through secondary enriched saline land, then entering the lakes. The surface water becomes brackish to saline as surface water passes through salt affected land. As the landscape salinity increases, the baseflow will also become saline.

Salinity resulting from groundwater discharge is currently not expressed within the majority of the catchment, as groundwater levels are typically >3m below surface. However, locally within the valley floors and low-lying areas to the east of Lakeland and Lake Bryde Nature Reserves, some salinity from direct groundwater discharge is occurring. With continued recharge to the groundwater system and inadequacy of the groundwater system to transmit the additional recharge, salinity resulting from rising groundwater will become more evident.

3.3 Previous Investigations

Salinity and waterlogging within the catchment has previously been assessed to varying degrees by AGWEST, CALM, catchment groups and other consultants.

AGWEST groundwater drilling has provided groundwater monitoring data. Surface water monitoring of the lake and surrounding areas has also provided surface water level and water quality data.

The majority of previous investigations have been completed to the south within the catchment with active catchment management groups.

Previous hydrology studies and information have been compiled from:

- Matt Giraudo – Hydrology of Lake Bryde, 1997
- Timothy Overheu, AGWEST – Results from Hydro Investigations, 1999
- Cecilia McConnell – Groundwater monitoring data
- Fay Lewis, AGWEST – Groundwater monitoring data
- Rosemary Knott, AGWEST – Groundwater drilling data, 1999
- CALM – Surface water monitoring of Lake Bryde during flooding, Jan 2000
- Water and Rivers Commission – Hydrogeology of the Newdegate Sheet, 1:250,000, 1999

Water and Rivers Commission database provided up to 100 monitoring, test and production bores within the study area. Most of these bores have not been completed as monitoring piezometers. Many bores were drilled during drought relief drilling program initiated by the Geological Survey of Western Australia in the1960s and 1970s.

Report conclusions concur that salinity is a major degrading process within the catchment and that it is likely to increase under current land management practices.

4. Natural Environment

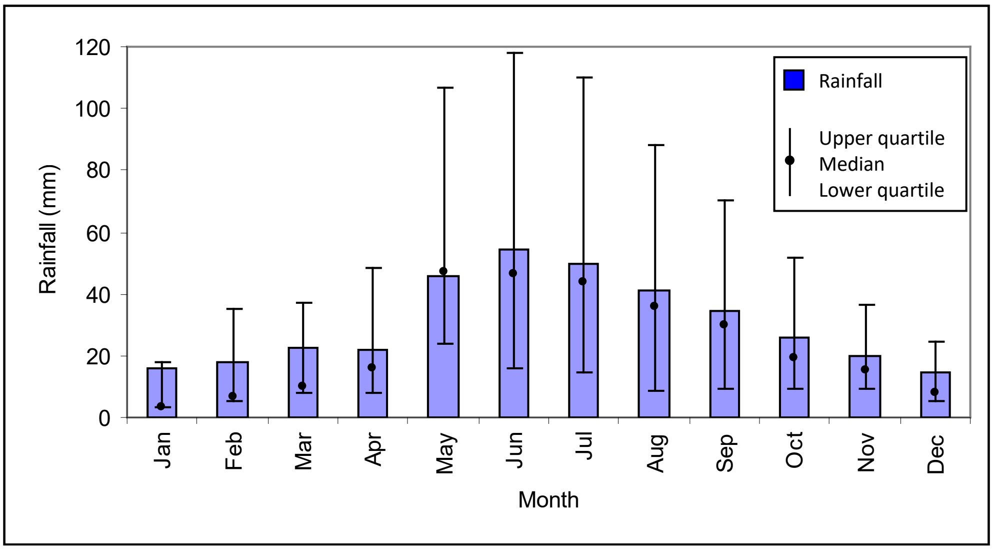
4.1 Climate

The study area is semi-arid with warm to hot summers and cold winters. It is estimated that the catchment receives an average annual rainfall of 350mm. The annual average rainfall for Newdegate is 380mm. Most of the rainfall occurs during the winter months, during the crop growing season.

The average monthly maximum temperature is 24°C and minimum temperature of 10°C. The monthly pan evaporation of Newdegate is approximately 2100 mm, and exceeds the average monthly rainfall for about 10 months of the year. Anecdotal information indicates that “significant” or episodic storm events occur approximately every 5 to 10 years. These events can occur during both summer and winter months.

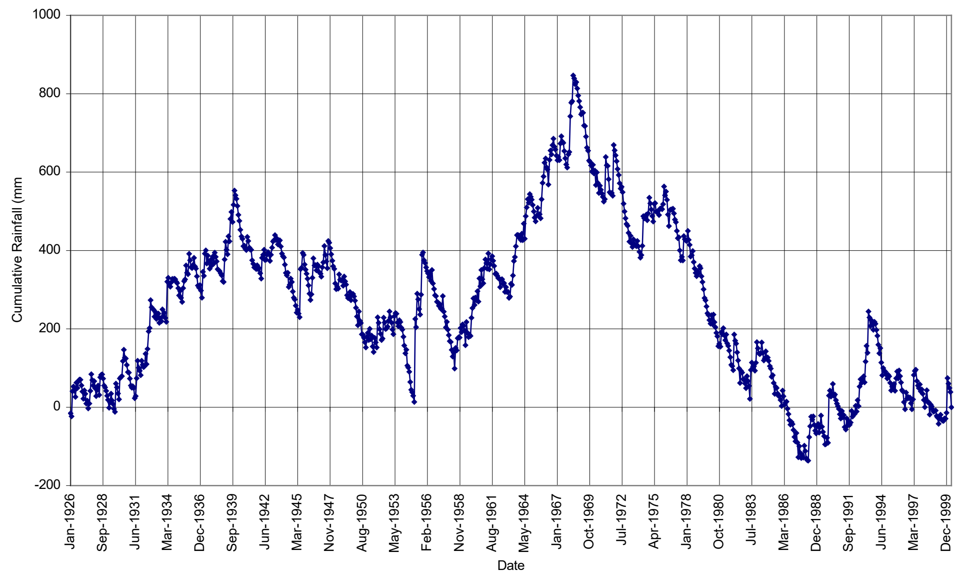
Rainfall figures for the groundwater monitoring period have also been superimposed to observe links between hydrograph response and rainfall. **Figure 4.1** illustrates monthly rainfall averages for the Pingrup station. It also presents the median and the difference between the upper and lower quartile rainfall totals.

Figure 4.1: Monthly rainfall averages



A residual rainfall curve was constructed based on rainfall figures recorded at the Pingrup station since 1926. This is illustrated in **Figure 4.2**. The residual rainfall curve is constructed based on the cumulative difference between monthly rainfall and monthly averages. The curve is useful to put in context recent rainfall data against historic fluctuations. It is apparent that rainfall figures over the last 5 years have been on the decrease and are below average. Therefore there are likely to be steeper rates of rise in average groundwater levels if heavy rainfall periods similar to that between 1958 and 1968 are again experienced.

Figure 4.2: Residual rainfall curve



Historically, the climate has played a significant role in the development of the catchment's landforms and hydrology. Beard, (1999) suggests that the drainage system flowed south during the Eocene. High rainfall during this period may have resulted in incision of deep drainage lines into the granitic basement and the deposition of sedimentary sequences. Salama (1997) suggested that during the Late Miocene and Early Pliocene, a dramatic decrease in ocean temperature, plus an increase in volume of Antarctic ice, would have led to a widespread precipitation decrease. A decrease in precipitation would have lead to the development of sand dunes across river courses forming lakes, such as Lake Grace. Wet and dry periods during the Pleistocene caused the erosion and local deposition of sediments that filled up river systems and the formation of lateritic duricrust.

With climatic changes river systems also stopped flowing and dried up forming salt lakes and playa lakes.

4.2 Regional Geological Evolution

The regional geological setting and the formation of the drainage systems has been described by numerous people including Geological Survey of Western Australia (1984) – Newdegate 1:250,000 geological sheet, Bettenay and Mulcahy (1971), Beard (1999), and Clarke (1994).

The entire area is underlain by Archean Granitoid basement rocks and weathering profile of the Yilgarn Craton. Proterozoic sedimentary rocks of the Albany-Frazer Origin occurs over 100km to the south. Proterozoic dolerite dykes intruded the granitoids, typically as swarms subparallel to the north west structural lineation between the Albany-Frazer Origin to the south and the Yilgarn Craton to the north.

Various Cainozoic sedimentary units overly the granitic and gneiss bedrock. Extensive weathering of the granitoid basement has resulted in deep lateritic weathering profiles.

Regionally, the geological and drainage evolution of the study area can be dominantly attributed to the break-up of Gondwana, which started from the Late Jurassic. Up until the late Cretaceous, basement weathering and reworking was occurring. The Lockhart system (comprising the Lake Bryde drainage system) was draining to the south, incising erosional valleys and canyons into the basement granitoids, potentially along northerly structural features generated by the separation of Antarctica from Australia. Sediments draining to the south were deposited into grabens over the area which is now continental shelf.

The increase in aridity and the continued northward motion of Australia resulted in a reduction in sediment deposition and the deposition of fluvial and colluvial sediments in valley floors further to the north (palaeochannel systems). This style of valley erosion and the deposition of sediments would have likely occurred within the southerly draining Lake Bryde palaeochannel.

With the ongoing separation of Antarctica, the sagging of the Australian continental margin created uplift during the mid to late Cretaceous causing the Ravensthorpe Ramp to develop and a reversal of the southerly drainage system. Southerly draining palaeochannels would have been truncated by uplift from the Ravensthorpe Ramp. The Lake Bryde upper catchment is located on the northern side of the Ravensthorpe Ramp.

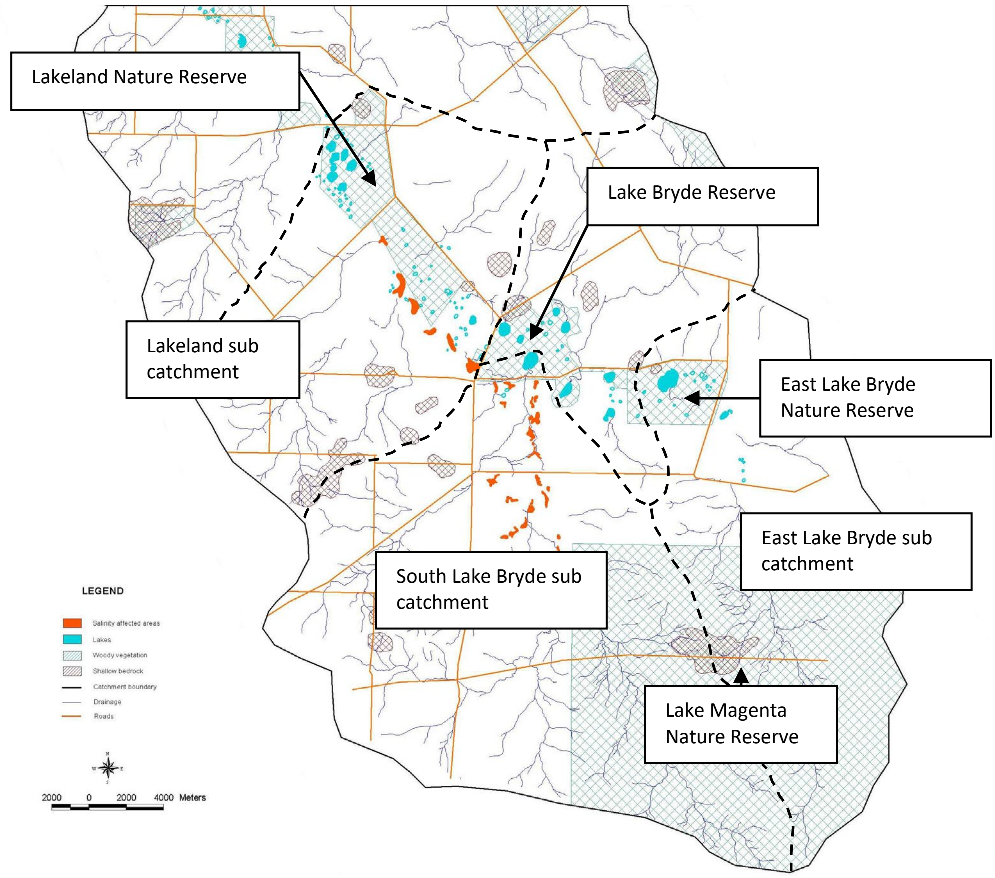
The change in drainage resulted in northerly flowing river systems along the previously southerly draining river systems and along rejuvenated drainage systems, depositing lacustrine, colluvial and fluvial sediments. Structural features would have accompanied, and possibly have been reactivated by the tectonic activity associated with different periods of uplift and separation.

In the Late Eocene, further marginal uplift brought up the Darling Range and caused a diversion of drainage within the upper Avon. The Lake Bryde catchment flowed gently north as part of the upper reaches of the Avon drainage system. Progressively, the depositional environment would have become more arid depositing lacustrine sediments and developing salt and playa lakes and aeolian sand dunes. Colluvial sediments would have been deposited as erosion and reworking continued.

4.3 Geomorphology

The geomorphology of the catchment consists typically of gently undulating topography with low relief rising from 390 mAHD to the west to 290 mAHD within the valley floors. The study area is approximately 65km long and roughly 16km wide and is much narrower than the surrounding Lockhart and Lake Grace catchments. Up to 4 sub-catchments have been identified within the study area, **Figure 4.3**.

Figure 4.3: Lake Bryde Catchment and Sub Catchments



In general, the study areas can be described as a broad ‘U’ shaped catchment with a flat valley floor up to 3 km wide and with gently undulating upslope divides. The width of the valley floor is variable due to features such as slightly elevated bedrock and truncated laterite profiles pinching and necking the lower topography.

Low relief and isolated drainage has resulted in an internally drained landscape, characterised by low flow gradients and poorly identifiable ephemeral drainage lines. Due to a shallowing of topographic gradient in the lower catchment (gradient from 0.004 in the lower slopes to 0.001 in the valley floors) drainage is limited and sluggish with lakes and wetlands developed within the broad valley floors. Colluvial and aeolian deposits have blocked surficial drainage in the lower catchment, resulting in the development of playa lakes and lunettes.

Overall, the landscape and topography within the catchment have developed from extensive weathering processes during the Late Tertiary and Quaternary. Important weathering features identified throughout the catchment include a deep lateritic and pallid weathering profile, truncated laterite and colluvial and aeolian deposits within the mid slopes and valley floors. Sand plains of variable thickness cover the majority of the catchment, eroded and truncated by weathering and the deposition of colluvium and alluvium, **Plate 9, Appendix F**. In general erosional modification by water has been most effective where slopes are steepest.

Detailed soil mapping has not been completed as part of the brief. However, in general the soils relate closely to the thin veneer of Tertiary and Quaternary geology, much of which is discussed above and in the following section, Catchment Geology. For the purpose of the study, the following soil units have been identified throughout the catchment:

- Deep White Sand Plains – pale grey deep reworked sands with some laterisation at depth, identified to the south east in isolated gentle hillocks.
- Yellow Sands – weathering product of laterite and some aeolian remobilisation, forming in isolated areas overlying laterite and sandy clays.
- Sandy Gravels –overlying mottled zones with some cementation. Identifiable down slope from ironstone outcrops in the mid to up slope areas of the catchment.
- Loamy Sands – shallow silty sandy overlying clayey alluvial and colluvial deposits within up slope and valley drainage depressions.
- Duplex Soils – sand over mottled or pallid clay are extensive over the mid slope areas and indicative of colluvium reworking and aeolian processes.
- Moort Soils – a shallow loamy sand, developed where pallid clays have been exposed, particularly to the south west and north east of Lake Bryde.
- Morrel – shallow loamy sands and silts overlying clays and identifiable in the low catchment in saline areas to the south east of the lakes.
- Heavy red soils – clayey loam over light clay and can form near dolerite dykes.

4.4 Catchment Geology

As outlined in **Section 4.2**, the geology of the catchment typically comprises of a granitoid basement overlain by up to 45m of lateritic weathering profile (saprolite) and colluvial and alluvial surficial sediments. The geology of the study area is shown on the **1:75,000 Hydrogeological Map**. Schematic cross sections of the catchment are shown in **Figure 4.4** and **Figure 4.5**.

4.4.1 Basement Granitoids

The Geological Survey of Western Australia, 1:250,000 geological series map of Newdegate indicates that the basement material consists of Archaean and Proterozoic Yilgarn Craton Granitoid Gneiss. The basement comprises strongly foliated and medium grained granodiorite with localised compositional variations. The dominant structural trend appears to be north north west with some east north east trends occurring within the outcrops to the south east.

Basement is exposed on the margins of the broad drainage valleys and as small monadnocks in the upper reaches to the south east and west of the study area. The basement appears to have been incised by the broad palaeochannel as an erosional feature. A review of available geological logs indicate that basement is typically at a depth of 30 to 40m below ground level below the palaeochannel. Differential weathering patterns and structural controls are likely to have controlled isolated areas of shallow basement and monadnocks.

Numerous Proterozioc dolerite dykes intrude the basement granitoids, and are typically orientated north east and north west in swarms. These dykes are extensively weathered and identifiable by areal photography and some ground truthing to the south of Ryans Road and to the north of the intersection of Newdegate Road and Fourteen Mile Road. The dykes appear as linear features up to 2km in length and are preferentially jointed along strike. Salinity appears to be associated with the dykes to the south of Ryans Road.

4.5 Weathering Profile

A deeply weathered rock and soil profile exits above the basement comprising of pallid clays, laterite and mottled. Historical geological logs provide little information to the character or consistency of the profile, however, the weathered zone may be up to 40m thick in parts, particularly in the area of the mid slope hills. The weathering profile, commonly referred to as saprolite or laterite, comprises of a mottled zone beneath the surface overlying a pallid clay horizon.

Ferruginous iron stone capping or siliceous cementation is isolated and truncated throughout the entire catchment, possibly representing the elevation of various former landscapes and groundwater levels. Exposed ironstone capping typically exists on top of ridges and above shallow bedrock and commonly comprises pisolitic gravels consolidated by a ferruginous cement.

Siliceous capping is also extensive particularly to the west, possibly representing areas where the laterite capping and mottled zone has been eroded and the pallid clays have been exposed and silicified. Further information regarding the shallow soil and weathering profile is outlined in **Section 4.4.1**.

4.5.1 Cainozoic Sediments

Sediments within the study area can be identified as Tertiary and Quaternary deposits and can be correlated to different periods of deposition, climate and direction of drainage.

Tertiary Deposits

Up until the Late Eocene, the depositional environment was controlled by southerly flowing river systems. Deposition was greatest within the palaeochannel located within the lower landscape flats. The alignment of the palaeochannel drainage and deposition appears to occupy a major lineament. The drainage channel has incised into the basement rock, eroding the weathered saprolite profile.

Early to mid Tertiary deposits lie unconformably over the bedrock and have been covered by late Tertiary and Quaternary sediments throughout the entire study area. The early to mid Tertiary sediments can be characterised as partly cemented and loose fluvial quartz sands and basal conglomerates interbedded with lacustrine clays, silts and lignites. An upward fining sequence is identifiable within the deposits, possibly indicating a change from fluvial to lacustrine depositional environments correlating directly with climatic and tectonic changes during this period.

Tertiary palaeochannel sediments have been encountered from about 25m to depths of at least 35m below the current ground level. The basal sands are likely to be part of the Werillup Formation. The channel is not considered to be one pervasive and direct channel but more likely to comprise of numerous interconnected and eroded flow paths representing a braided stream system. The channel may also have been truncated by faulting, transecting the palaeochannel directly south of Lake Bryde.

During the development of the Ravensthorpe Ramp the Tertiary palaeochannel deposits may have been dissected along the axis. There is the possibility that the palaeochannel extends through both the Lake Bryde and the southerly draining catchment to the south. However, given the palaeochannel is around 35m thick and an elevation difference >40m extends from the upper to lower catchment, the palaeochannel deposits may have been eroded or truncated.

Late Tertiary and Quaternary Deposits

From the Late Tertiary onwards the landscape has been deeply weathered and eroded to low relief. The late Tertiary and Quaternary sediments cover the entire catchment, exposing older Tertiary deposits and Archaean basement where the profile has been eroded.

The broad drainage channel deposits comprise of valley fill clayey, sandy and silty lacustrine and detrital sediments, sand plains, reworked Tertiary colluvium deposits and lateritic duricrust. The broad valley floors have suffered frequent aeolian modification with the development of bare playa surfaces and flanking deposits in the form of lunettes and sand plains. The lunettes have formed on the south eastern sides of the dunes down gradient of the prevailing depositional wind direction.

Deep and shallow sandplains cover approximately 50% of the catchment study area, thickest along the eastern slopes to the south east of Lake Bryde. The sandplains form rounded and undulating hillocks up to 5m thick and consist of aeolian and alluvial sands.

Reworked colluvium and water laid alluvium is deposited in secondary drainage valleys. These secondary valleys adjoin the primary palaeochannel are thinner in the upper catchment, occupying poorly defined drainage channels. The thickness of these recent alluvial deposits varies from 2 to 15m. In the heads of the valleys, adjoining sandy uplands, coarse sandy wash frequently overlies older more clayey deposits. The alluvial and colluvial valley deposits typically overlie and truncate lateritic and pallid clay profiles. Drilling in the mid to upper West Lake Bryde sub-catchment encountered colluvial deposits at depth of 10m beneath clayey valley fill deposits.

Within the remainder of the catchment, extensive areas of sandy soils overly deep, leached, mottled and pallid zones. Where the sandy soils have been intersected by areas of drainage and erosion, the laterite is preserved as spurs or as truncated residuals of pallid zones. Iron stone has also been identified at different levels within the landscape, indicating numerous periods of erosion and deposition.

4.5.2 Structural Geology

Numerous structural features have been identified within the catchment. As a result of the structural deformation, the basement may have well developed and pervasive fracturing pattern. Re-activation of faulting along similar orientations may occur in the catchment.

The primary palaeochannel deposit was likely to have been orientated along a fault zone, which probably extended through the current catchment divide. The fault has been called Bryde Fault. With the development of the Ravensthorpe Ramp and the uplift of the Darling Scarp numerous structural features may have developed or reactivated, cross cutting the primary palaeochannel.

Ryans and Bryde Faults have been identified trending north west orientated parallel to the primary palaeochannel. A Proterozioc dolerite dyke swarm has been identified with the Ryans Fault zone. Salinity is also associated with these structures. The South Lake Bryde sub-catchment drainage is orientated along Ryans Fault and appears to be truncated to the north by another westerly trending Lockhart Fault.

The north easterly trending Magenta Fault has also been identified from aerial photographic interpretation and previously from AGWEST investigations. The

Lockhart and Magenta Faults intersect in the vicinity of East Lake Bryde and may represent conjugate features. It is also possible that the Tertiary drainage pattern in the study area has been extensively influenced by these faults. Firstly, the Magenta Fault appears to have transected the primary palaeochannel, offsetting the southerly section of the channel to the east with a component of downward oblique movement. This is supported by a greater thickness of Quaternary alluvial and extensive aeolian deposition in this region. Secondly, the Lockhart fault zones appears to postdate the Magenta Fault, causing some reversal of the Magenta Fault offset. Rejuvenated drainage appears to follow the orientation of the Lockhart Fault to the south west and north east of Lake Bryde.

4.6 Surface Water Drainage

Surface water flow through the catchment is poorly defined and ephemeral. Drainage can be divided into the following categories:

- Broad valley sheet flow
- Mid and up slope valley sheet flow
- Up slope hillside creep

Surface water runoff and flow in drainage lines migrates down the catchment and discharges into wetlands and lakes in the broad valley flats. The broad and mid slope valleys have poorly defined drainage lines and swampy conditions develop where low or at a change in gradients. Much of the low lying areas within alluvial valleys are seasonally waterlogged and inundated.

The lakes in the valley floor typically behave as closed systems during average rainfall events, with recharge originating from localised surface water runoff. With increased periods of rainfall, the lakes can become full and the water level cascades through natural spillway features, discharging water into the down gradient lakes or wetlands. Surface water runoff volumes have increased since clearing, resulting in the more frequent flooding and filling of the lakes and surrounding wetlands. The hydrology of the lakes is controlled by their morphology, discussed in the following sections.

In the mid and up slope regions drainage usually occurs along or within the existing drainage channels reactivated after the clearing of vegetation. A review of aerial photographs prior and after clearing demonstrates that many drainage channels were not present prior to clearing. Drainage lines flow infrequently during periods of heavier than average rainfall.

Drainage features do not always intersect the broad valley areas. In the south east of the Lake Bryde catchment, in the sand plains of East Lake Bryde sub-catchment drainage is limited. Surface water drainage features originating from Lake Magenta Nature Reserve and the surrounding slopes terminate when they intersect the sand plains of the lower catchment. Surface water recharges into the groundwater at this point.

4.7 Lakes

Playa Lakes

Scattered small lakes and wetlands occupy the valley floors. Many of the lakes are relatively small, shallow, circular depressions and not in direct connectivity with the surface water drainage, eg Lake Bryde and other lakes to the east of the broad drainage flat. These lakes have been characterised as playa lakes and appear to have been fresh to brackish and have clayey bases, potentially with layers of gypsum. Large lunette dunes with moderately developed soil profiles and vegetation are identifiable along the south eastern margins. Lunette patterns indicate that the lakes have migrated to the north east over time. The vegetated lakes typically have lower salinities due to less evaporative processes.

Some of these lakes have become saline due to increases in salt enriched runoff entering the lakes during peak rainfall periods. Other playa lakes, north of Lake Bryde are experiencing saline groundwater discharge, resulting in saline conditions developing. Playa lakes located near clearing have a higher range of electrical conductivities from 300 to 15,000 μs/cm.

Sand Plain Lakes

Isolated lakes have also developed in the east of the Lake Bryde catchment as scallop shaped features in the deep sand plains on the valley floor, eg East Lake Bryde. These lakes are recharged by sand plain seepage and localised runoff. The lake base comprises of clayey alluvial sediments. Anecdotal evidence indicates that these lakes are poorly connected even during peak rainfall periods. The smaller sand plain lakes are vegetated.

In general, electrical conductivities range from 2000 to 11,000 μs/cm. Sand plain seepage lakes are saline where the surrounding vegetation has been cleared for agricultural purposes. A good example of a sand plain lake now saline is the small lake 2km east of Lake Bryde along the Newdegate Pingrup Road.

Drainage Lakes and Wetlands

Other smaller lakes, which are in direct connectivity with the drainage system occur on the western side of the valley floor or in the drainage depressions. These lakes are very shallow and have low lunette features on the south eastern margins and surface water runoff from western agricultural areas discharge into the lakes during periods of higher than average rainfall. Wetlands and swampy environments surround these features, including species of leptospermum, melaleuca and eucalyptus.

Many of these lakes and wetlands are saline with electrical conductivities as high as 30,000 μs/cm.

4.8 Processes of Soil and Water Deterioration

4.8.1 Salt Load Runoff

Secondary salinity occurs in the catchment from evaporation of poorly drained and water logged soils and in isolated areas from shallow localised and saline groundwater levels. Following periods of rainfall, the runoff becomes enriched in salts. The enriched runoff discharges into lakes and wetlands, resulting in the deterioration of the water and soil quality. Changes in lake water quality is expected from variations in salt load runoff. A substantial increase in the salinity of Lake Bryde was reported during 1992, correlating to an episodic rainfall event.

Field investigations indicate that shallow lakes, wetlands and soils surrounding cleared land that are in hydraulic connectivity with surface drainage have suffered some form of salinity, whilst lakes that are not connected with the drainage system remain fresh.

Epicormic growth on some vegetation in and surrounding lakes indicates that some salt stress may have occurred previously from pulses of salt enriched water inflow.

4.8.2 Groundwater Discharge

Monitoring of groundwater beneath the lake and wetland systems indicates that the regional and localised systems are saline. Increased recharge in the surrounding catchment and waterlogging in the lower areas of the catchment have resulted in the rise of groundwater levels and the upward mobilisation of salts.

Where the groundwater levels are shallow, eg <1m or where they intersect the surface, soil and water resources can become impacted by salinity resulting in the deterioration of lakes and wetlands.

Groundwater levels are rising and appear to have intersected some of the lower landscape features, such as lakes. Groundwater is discharging through the base of numerous lake systems, resulting in lake deterioration and salinisation, eg lake 1km north west of Lake Bryde. Lakes which are dry are likely to be areas of net groundwater recharge, primarily because a hydraulic head of water is not present to reduce discharge seepage. However, given the base of the lakes are clayey, capillary rise is likely to contribute to the dominant mechanism of salt concentration in these lakes.

4.9 Remnant Vegetation

Approximately 36% of the catchment is covered by remnant vegetation, the bulk being in the Lake Magenta Nature Reserve to the south east and within the reserves along the valley floor, **Figure 3.1**.

The remainder of the catchment has isolated pockets of remnant vegetation, much of which has not been represented on report figures.

Some revegetation has been completed within the lower and mid slope regions to alleviate waterlogging.

Some remnant vegetation in the lower slopes has been impacted by saline surface waters. These areas include the waterlogged areas directly south west of Lake Bryde and to the west of Lakeland Nature Reserves.

5. Hydrogeology

5.1 Groundwater Occurrences and Flow

Groundwater occurs within regional and localised aquifers within the catchment. Groundwater occurrences have not been identified within the upper catchment and these areas are considered to have limited to no groundwater resources.

The water table mimics a subdued image of topography over most of the catchment with isolated variations due to localised recharge/discharge features. In general groundwater flow is along a very gentle gradient towards the broad valley flats, shown on the **1:75,000 Hydrogeology Map**.

For the purpose of the study groundwater occurrences have been identified in three aquifers:

- Fractured rock aquifers
- Tertiary aquifers
- Quaternary or surficial aquifers

These aquifers are considered to have some hydraulic connectivity. However, connectivity is considered to be low over the majority of the catchment with isolated areas of greater interconnectivity from permeable lithologies or structural features.

Localised ephemeral or perched aquifer systems have been identified within the surficial deposits and may not be in direct hydraulic communication with other more extensive aquifers.

Groundwater throughflow from the catchment study area would ultimately occur to the north through the valley floor sediments.

5.2 Aquifer Characteristics

5.2.1 Granitoid/Saprolite Aquifers

The fractured rock aquifer underlies the entire catchment. Groundwater occurrences have been identified within fractured fresh rock and within saprolite weathering discontinuities. The aquifer is considered to be semiconfined.

Much of the weathering profile is unsaturated throughout the mid to upper catchment. Highest yields of groundwater is likely to be encountered within the regolith and relatively minor yields encountered within the overlying saprolite clays. Higher yields may also be available from structural features such as faults. However, due to a lack of bedrock drilling information fresh rock and regolith yields are unknown but are likely to decrease with depth.

Permeability testing of this material indicated hydraulic conductivities ranging from <0.005 to 1 m/day. Groundwater flow would be generally along pervasive relic fractures and joints and secondary permeability along weathering features at the base of the saprolite.

Recharge is considered to be relatively low and via direct rainfall recharge or via leakage from overlying alluvium and colluvium.

5.2.2 Tertiary Aquifers

Groundwater occurrences within the Tertiary deposits has been identified within the palaeochannel by exploration drilling. The Tertiary aquifer is semiconfined and is likely to be recharged from leakage from the overlying alluvial sediments and potentially underlying fractured granitic rock aquifers. Direct rainfall recharge is considered to be minimal due to no identifiable outcrop.

The extent of the aquifer is unknown but it is expected to follow the palaeochannel feature. Lithologically, the aquifer comprises clays, sands and gravels. High groundwater yields are expected in the coarse grained basal sediments. Lower yields are likely to be expected in the overlying and more extensive clayey sediments. The sand and clayey lithologies are likely to be interbedded and in parts truncated by braided depositional environments.

Dobson, 1999 indicates the thickness is variable and thins at the margins. Drilling results indicates up to 10m of sand and gravels at the base of the formation. The sandy basal unit would be high yielding and given the depositional and erosional environment, may be in hydraulic communication with surrounding aquifers.

Aquifer hydraulic conductivities in this unit are likely to be variable. Commander et al, 1992 indicated hydraulic conductivities of 20 to 70m/day within the Wollubar Formation. Dobson, 1998 suggests similar hydraulic conductivities may exist within the palaeochannel deposits due to similarities in aquifer lithologies and depositional environments. Permeability testing in the clayey sequences has indicated lower hydraulic conductivities in the order of 0.001 to 0.1 m/day.

5.2.3 Surficial Aquifers

The surficial aquifers comprise of Late Tertiary and Quaternary sediments deposited over the majority of the catchment. The majority of exploration water bores and monitoring piezometers have been drilled into the surficial deposits. The aquifers have variable flow characteristics and thicknesses and can be hydraulically isolated, due to weathering and depositional features. The aquifers include:

- Valley floor and mid slope alluvium.
- Sandplains.
- Hill slope scree and colluvium.

In general the thickness of these aquifers is variable probably increasing towards the lower catchment. Drilling results and field mapping indicated that these aquifers range from 2m to 20m thick, with clayey sequences deposited towards the lower catchment and within the centre of low energy drainage flats. Sandy deposits have been identified within the upper catchment drainage depressions, down slope of granitic and lateritic outcrops and in lower catchment primary drainage features.

Permeability testing has been limited within these aquifers, however values are considered to be variable, ranging from <0.001 to 1 m/day. Higher values may be encountered within coarse grained sediments at depths in the lower catchment. Groundwater yields are considered to be typically low however, relatively higher yields were encountered in monitoring bore LBE8 where airlift yields of 4 L/sec were reported (Knott pers comm, 2000). However, this bore may have intersected Tertiary sediments.

Recharge to these aquifers is directly from rainfall infiltration and waterlogging infiltration.

5.3 Groundwater Monitoring Data

Groundwater monitoring data for the Lake Bryde catchment was sourced from both CALM and AGWEST. A number of bores exist within the catchment, not all of which are periodically monitored. A new set of bores have also been recently constructed in the East Lake Bryde sub-catchment. A summary of all the bores within the catchment is provided below. Natural surface levels for the bores have been obtained from the recently produced digital elevation model for the Lake Bryde catchment. **Appendix H** presents monitoring bore and piezometer construction details.

The bores marked UB1 to UB4 were unidentified bores within the Lake Bryde east catchment.

Figure 5.1 presents a bore location map for all the bores listed above.

Hydrographs for bores which have been periodically monitored are presented in **Appendix A**. Raw monitoring data is also provided in **Appendix A**. Note that bores LB1 through to LB6 have been monitored using data loggers. For purposes of data management, this data has been filtered to monthly readings.

5.4 Hydraulic Testing

Rising/falling head tests were completed within a number of piezometers in the Lake Bryde catchment to enable assessment of a hydraulic conductivity. The data was analysed using Bouwer and Rice (1976) and Hvorslev (1951) equations to calculate the bulk hydraulic conductivity using the computer package Aquifer Test. Complete details of the results are provided in **Appendix B**.

Figure 5.2 illustrates bores which had permeability tests completed. The size of the marker is proportional to the magnitude of the hydraulic conductivity. A summary of the results is presented in **Table 5.1** below.

Figure 5.2: Aquifer Test Locations

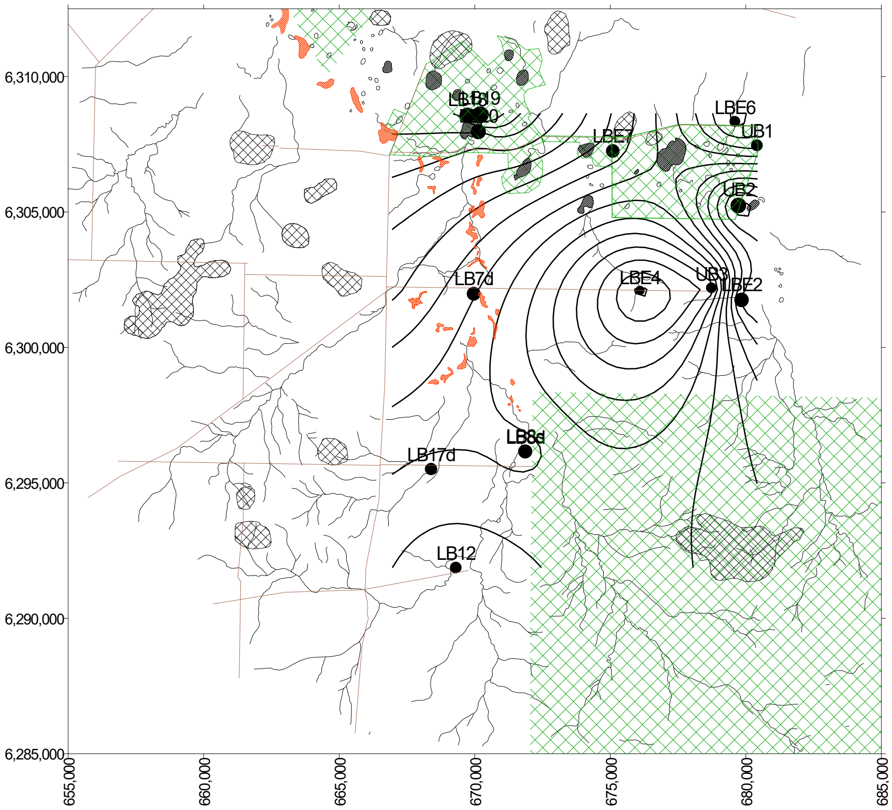


Table 5.1: Hydraulic conductivities

Bore ID	Easting	Northing	Hvorslev K (m/day)	Bouwer & Rice K (m/day)
LB8d	671869	6296158	0.0116	0.0181
LB18	669732	6308561	0.2557	0.3335
LB19	670212	6308585	0.8528	1.0714
LB20	670139	6307958	0.1305	0.1763
LB7d	669967	6301981	0.0435	0.0695
LB12	669307	6291872	0.0045	0.0070
LB17d	668397	6295511	0.0090	0.0145
LB8s	671869	6296158	0.0546	0.0804
LBE2	679850	6301750	0.0873	0.0968
LBE4	676100	6302100	0.0005	0.0008
LBE6	679604	6308344	0.0021	0.0025
LBE7	675100	6307250	0.0320	0.0494
UB1	680416	6307460	0.0051	0.0065
UB2	679733	6305240	0.2320	0.2544
UB3	678736	6302200	0.0017	0.0027

5.5 Groundwater Depths

Historical monitoring data from piezometers in the South Lake Bryde and East Lake Bryde sub-catchments is available. Limited groundwater information is available over the remainder of the catchment. The interpretation of information compiled from the south of the catchment has been extrapolated to the remainder of the catchment.

Depths to groundwater range from 1.85m to 27m below ground level. Shallow groundwater levels have been identified within the lower catchment surficial aquifers. In the saprolite aquifers of the upper catchment the depth to water is the greatest. The majority of piezometers in the lower catchment and mid slope areas show a rise in groundwater levels in response to increased recharge. Piezometers which have not risen may be monitoring localised perched conditions or isolated aquifers with high transmissivities.

Above the 350mAHD the alluvial and saprolite aquifers are thought to be unsaturated.

Nested piezometer information indicates that slight downward piezometric heads are reported within the upper catchment bore LB10i and LB10s and within lower catchment bores LB7s and LB7d. This may indicate groundwater is recharging in these areas. Variations of up to 5m in water levels at LB7 deep and shallow bores may indicate that the surficial aquifer has isolated groundwater systems.

All other nested bores show similar water levels between deep and shallow bores. This may indicate unconfined conditions or poor bore construction.

Groundwater levels in the saprolite aquifers are deeper than the overlying surficial aquifer, indicating possible localised perching conditions in the overlying surficial sediments.

Groundwater levels within the surficial aquifers in the broad valley flats are shallow and potentially discharging into lakes and wetlands to the north west of the valley floor where large areas of salinity occurs.

5.6 Hydrograph Interpretation

A total of 16 piezometers at 13 sites have sufficient water level monitoring information to enable hydrographs to be produced and interpreted. At three sites LB8, LB9 and LB2, nested bores are available. Hydrographs for each piezometer and rainfall for Pingrup are provided in **Appendix A**. The monitoring covers the period from mid 1995 to present. Some gaps are present in a third of the bores from 1996 to 1999. These bores are typically located within the east and west catchment, within alluvial and saprolite aquifers from the upper to the lower catchment and are considered to be representative of the remaining catchment. The hydrograph sets provide short term water level information. Long term monitoring data would provide a greater value to hydrograph interpretation. However, for the monitoring period the hydrographs indicate:

- Piezometric levels and recharge were variable;
- Total recharge increased with increasing mean annual rainfall;

- Most recharge or rises in hydrographs occurred during early parts of winter with the exception of summer storm events;
- All vegetated areas responded to rainfall and recharge; and
- Recharge probably occurs from direct infiltration.

Hydrograph variations may be due to a number of factors including:

- Aquifer transmissivity and leakage from overlying semiconfining conditions;
- Soil water storage, ponding and runoff;
- Preferential flow conditions;
- Rainfall and evaporation;
- Vegetation coverage; and
- Location in the catchment.

Continued Rising Trends

Continued rising trends with minor downward trends were observed in LB01, LB2d, LB2id, LB07d, LB12, LB16 and LB17. These bores are located within the surficial and saprolite aquifers in the Lakeland and South Lake Bryde sub-catchments, where topographic and hydraulic gradients are lower and surficial aquifers overlie the saprolite aquifers. Extensive clearing of woody vegetation has occurred in these areas.

Shallow and deep piezometer hydrographs responded similarly, with some delayed responses occurring in the deep piezometers (LB2) possibly due to slow downward leakage. The deep piezometers demonstrated a more consistent upward trend from 1997 onwards. In general downward trends were typically less than 25% of the overall upward trend for the monitoring period and coincide with dry periods where recharge or aquifer leakage was minimal. Following episodic recharge events, piezometric levels did not recover to pre episodic levels.

These piezometers are recharged both by episodic and regular rainfall, possibly via the overlying alluvial aquifer and at the change of gradient where surface water ponding occurs and run off decreases. The piezometric levels are also likely to be maintained via the hydraulic gradient within the upper catchment and a reduction in transmissivity in the lower to mid catchment.

Variable Trends

Hydrographs for LB3D, LB10, LB18, LB19 and LB20 show a similar response to recharge with strong upward trends occurring during 1996 and 1997 followed by seasonal peaks and troughs with an overall slight upward trend in the majority of piezometers for the remainder of the data. Hydrograph peaks correspond to intense recharge events and troughs to dry periods.

Piezometer LB10 is located in the vegetated upper catchment and LB18, LB19 and LB20 are located in the surficial aquifer of the lower catchment surrounding Lake Bryde; opposing ends of the catchment. Piezometer LB10 appears to be more static relative to the other piezometers, recovering quickly following high rainfall events. The lower catchment bores recover more slowly possibly due to delayed throughflow recharge and soil water leakage.

Piezometer water levels in LB18 and LB19 increased by up to 3.5 m in 1998, potentially from a large scale water balance change in the catchment or a localised confined aquifer response.

In general these piezometer trends are variable, responding to rainfall recharge throughout the entire aquifer thickness.

Other Trends
Nested piezometers LB8 and LB9 have insufficient data to enable a trend to be properly defined, however, there appears to have been an increase in piezometric levels since 1995. The last 2 years of data may suggest the piezometric levels are relatively static, responding slightly to seasonal recharge.   The downward hydrograph trough shown in LB8 deep and shallow during August 1999 may indicate that the aquifer is relatively transmissive and without an elevated piezometric head.

5.7 Groundwater Flow Directions

Groundwater level data has been contoured and flow direction extrapolated on the 1:75,000 Hydrogeological Map. Localised or perched flow variations are not considered as part of the contour plan. The contouring is broad and many isolated variations are unlikely to be defined due to a lack of data density.

Generally, groundwater flow mimics the topography, flowing towards the lower landscape. Groundwater contours range from 390 mAHD in the upper catchment to 290m AHD in the lower catchment. Groundwater flow gradients are variable due to changes in aquifer transmissivities along the flow path and range from 0.0015 to 0.002.

The contour information indicates that the groundwater systems are typically discharging in the lower palaeochannel. Contours in the lower catchment indicate increased groundwater gradients from changes in aquifer recharge, geometry and or lithology.

A groundwater mound appears to have developed to the south east of Lake Bryde within the deep sand plain deposits. The mound is an expression of increased recharge and localised aquifer storage. The recharge mound is a naturally occurring feature due to the deep sandy lithologies overlying clayey alluvium, however excess runoff from the cleared areas to the south is likely to have contributed to the mound.

5.8 Surface Water Quality

Surface waters salinities are variable, with electrical conductivities ranging from <1,000 to >75,000 us/cm. Highest salinities were reported in lakes to the west of the Lakeland Nature Reserve and isolated deeper lakes to the south. Salinities are typically resulting from surface water infiltration and evaporation, however, some groundwater discharge may be occurring where groundwater levels or capillary rise intersect the base of the lake.

Vegetated lakes have lower salinities due to lower evaporative rates. Lake salinity variability appears to correlate with lake size, morphology, drainage discharge and recharge and vegetation.

5.9 Groundwater Quality

Ongoing groundwater samples have been collected from existing monitoring bores and analysed for pH and electrical conductivity. As part of this study groundwater samples were collected and analysed for a full suit of water chemistry parameters.

5.9.1 Catchment Groundwater Salinity

May 2000 monitoring information indicates that groundwater electrical conductivities range from 1,500 μs/cm to >80,000 μs/cm. Lowest values were reported within the mid slope colluvial deposits. Highest values were reported within the lower catchment flats in the surficial sediments surrounding Lake Bryde.

Monitoring bores LB10 and LB11, located within the saprolite aquifer in the vegetated upper catchment have groundwater electrical conductivities of around 50,000 μs/cm. Electrical conductivities in other upper catchment saprolite bores range between 50,000 and 60,000 μs/cm. Since the depth to groundwater is greater than 10m, these values may represent background salinity levels in saprolite aquifers.

Surficial aquifers in mid slope and alluvial valleys have groundwater electrical conductivities typically between 25,000 and 50,000 μs/cm, which are generally lower than the surrounding saprolite aquifers. This is probably a consequence of increased fresher rainfall recharge to these aquifers. Isolated zones of lower electrical conductivities have been identified within a surficial aquifer located along the eastern margin of South Lake Bryde sub-catchment, Map 4. This has also likely resulted from fresh water recharge through more permeable alluvial and colluvial sediments. This area may have higher rates of recharge.

Another fresher zone has been identified in surficial sediments to the east of the catchment beneath the sandplain deposits, potentially representing another zone of greater recharge. These fresher waters may be more extensive than portrayed on 1:75,000 Hydrogeological Map due to a lack of spatial information.

Electrical conductivities of groundwater within the palaeochannel and overlying surficial aquifer reflects salt enriched groundwater and fractionation/evaporative processes.

5.9.2 Catchment Hydro-chemistry

A number of samples were collected both from piezometers and surface water bodies within the Lake Bryde catchment. Samples were analysed on site using portable equipment for the following parameters:

- Electrical conductivity (EC) – mS/cm;
- Salinity (S) – ppt;
- Temperature (T) - °C;
- Turbidity (Tu) – ntu;
- Dissolved oxygen (DO) – mg/L and Dissolved oxygen % saturation (DO%);
- Oxidation/Reduction Potential (ORP) – mV; and
- pH – pH units.

A summary of the testing results is presented in **Table 5.2**. The complete data, together with a description and location of sampling points may be found in **Tables C1** and **C2** - **Appendix C**. **Figure C1 – Appendix C** illustrates the location of sampling points for the bores and lakes.

Table 5.2: Summary results of testing

	EC (μS/cm)	Temp (°C)	Turb (ntu)	DO (mg/L)	DO (% sat)	ORP (mV)	PH	Sal (ppt)
Bores (18 sampling points)								
Average	54 500	12.9	203.9	10.0	144.9	186.0	5.9	36.8
Stdev	21 100	1.3	233.5	8.7	131.1	176.4	1.3	15.3
Max	80 000	13.9	600.0	20.0	300.0	607.0	7.9	59.6
Min	1 700	9.4	0.0	0.7	4.6	-136.0	3.7	0.9
1st quartile	49 200	13.0	19.0	1.1	18.0	129.3	5.2	32.1
Median	57 900	13.4	86.2	6.5	80.7	186.5	6.4	38.6
2nd quartile	68 100	13.6	329.4	20.0	300.0	231.5	6.8	46.4
Lakes (12 sampling points)								
Average	6 200	6.0	127.4	18.9	247.9	53.2	9.1	3.4
Stdev	4 900	1.7	224.3	3.5	82.8	74.9	0.9	3.0
Max	15 000	10.2	600.0	20.0	300.0	205.0	10.3	8.8
Min	500	4.0	0.0	7.7	59.2	-104.0	7.2	0.3
1st quartile	2 200	4.6	0.0	20.0	185.5	25.0	8.7	1.1
Median	5 400	6.2	21.9	20.0	300.0	41.5	9.1	2.8
2nd quartile	9 000	6.5	100.8	20.0	300.0	85.5	9.6	4.9

A selection of the samples were also dispatched at a NATA registered laboratory for analysis of dominant cations and anions and water quality parameters:

- Cations – Na, K, Ca, Mg, Fe;
- Anions – CO3, HCO3, SO4, Cl1 ;
- Water Quality – pH, EC, TDS.

Table 5.3 presents a summary of each of the major cations and anions which were analysed for.

Table 5.3: Water Quality Parameters, ions (Boulton & Brock, 1999)

Compound	Description
K^+	Originates from weathering of some feldspars but does not remain in solution as well as Na^+. K^+ also tends to form micas which are insoluble, rendering the K unavailable to aquatic ecosystems.
Mg^{2+}	Is found in silicate and non-silicate minerals. The ratio of Ca and Mg varies in response to evaporation and changes in pH and CO_2. Loss of CO_2 and the rise in pH forms precipitation of $CaCO_3$ while Mg compounds stay in solution. During evaporation, Mg salts stay in solution longer than Ca salts.
Ca^{2+}	Occurs in many inland waters as $CaCO_3$. Ca can also react with sulfate to form gypsum ($CaSO_4.2H_2O$) and anhydrite ($CaSO_4$). These minerals found in sedimentary beds generally have marine origins but also come from evaporating salt lakes.
Na	Predominates in many Australian inland waters. This alkali metal is very reactive and highly soluble. Many igneous rocks contain Na such as feldspars. Sodium sulfites and sodium carbonates also yield Na in solution and originate from past evaporative events. In arid areas, there are sodium chloride dominated salt lakes.
SO_4^{2-}	Second most common anion in seawater. Elemental S is inactive at ordinary temperatures and oxidises to various forms of SO_2, SO_3^- and SO_4^{2-}.
CO_3^{2-}	Occurs most often as bicarbonate (HCO_3^-) and with Ca as $CaCO_3$ (eg. calcite). Other common forms of carbonate are magnesite ($MgCO_3$) and dolomite ($CaMg(CO_3)_2$).
Cl^-	Most common anion in Australian inland waters. Usually Cl combines with Na to form common table salt (NaCL) but it may combine with Mg ($MgCl_2$). "Cyclic chloride' comes from evaporites – extensive beds os salt from evaporation of waters where it has been in oceans at least once before and it will return, whereas 'juvenile' chloride has never circulated and is found in water newly released from minerals or dissolved in igneous rock.

A summary of the results is again presented below, **Table 5.4**. The complete results may be found in **Table C1 and C2 – Appendix C**. **Appendix C** also presents more detailed statistics and percentage exceedance plots for the water chemistry results.

The pH of groundwaters range from 3.8 (acidic) to 7.8 (neutral). The majority of groundwater pH is acidic to weakly acidic. Surface waters are typically neutral to alkaline ranging from a pH of 8 to 10.3.

There are a number of plots which may be generated to interpret the results of the water chemistry analysis. **Figures 5.3** to **5.5**, Piper plot, Water Type diagram and Durov plot are three such ways. The plots also include data from a number of bores installed by the Water and Rivers Commission. This data together with the construction details of a number of monitoring bores in the catchment was sourced from the agency.

Table 5.4: Summary of laboratory analysis results (mg/L)

ID	Na	K	Ca	Mg	Fe	CO_3	HCO_3	SO_4	Cl
Bores (16 samples)									
Average	12640	135	207	1512	5.3	1.0	107	2997	20368
Stdev	5016	57	176	673	8.0	0.0	128	1491	8081
Max	19000	220	690	2800	29.0	1.0	420	6900	32000
Min	240	10	12	30	0.1	1.0	5	36	390
1st quartile	10750	106	91	1100	0.5	1.0	5	2475	17000
Median	14000	135	195	1650	2.3	1.0	70	3300	23000
3rd quartile	16000	183	228	1850	5.7	1.0	153	3425	25250
Lakes (6 samples)									
Average	965	32	92	100	0.5	1.0	192	258	1580
Stdev	911	18	94	95	0.7	0.0	94	264	1567
Max	2100	50	260	220	1.5	1.0	360	690	3600
Min	30	11	12	8	0.1	1.0	80	30	42
1st quartile	180	18	31	19	0.1	1.0	155	73	220
Median	865	32	58	79	0.2	1.0	170	150	1310

It can be clearly seen from **Figures 5.3** to **5.5** that the majority of the samples collected from bores and lakes are end product water, typically sodium chloride type. Groundwaters are consistently sodium chloride waters whilst surface waters are more variable, but essentially sodium chloride waters, with calcium, magnesium and bicarbonate components. The piper diagram shows that some lake waters and groundwaters plotting in a similar position, representing similar waters and potentially mixing trends.

Boulton and Brock (1999) explain that most waters in Australia, especially those with high conductivities, are dominated by Na and Cl whereas Ca and CO_3 dominate 'world average fresh water'. Only for the fresher lakes is there a deviation from the Na-Cl domination when Mg and HCO_3^- become dominant. Lakes that deviate from the norm of sodium chloride domination may have gained their ions from weathering of certain rock strata or from evaporative concentration and selective precipitation of particular salts (Boulton & Brock, 1999). This may be the case for the surface water SL1 where magnesium is proportionally higher.

Groundwater types are consistent, even with the lower salinities demonstrating Na Cl dominance. With age, chemical interaction and evaporation the chemical composition of groundwater changes from HCO_3 dominant to Cl dominant. This trend has not been observed in groundwater bores along the flow path, indicating the majority of recent recharge has been mixed with enriched saline groundwater and dissolved salts leached through the soil profile.

The source of sodium chloride is from percolating rainfall leaching minerals out of the soil and rock profiles as well as through evaporation processes.

5.10 Aquifer Flow Dynamics (conceptual model)

5.10.1 Groundwater Recharge

Recharge occurs throughout the entire catchment. Recharge to the groundwater systems occurs through:

- Direct rainfall infiltration;
- Recharge from waterlogged soils; and
- Flow and leakage between aquifers.

A portion of rainfall will directly infiltrate the shallow soils and rock profile as recharge. The recharge percentage will depend upon rainfall, vegetation, runoff coefficients and permeability of soils.

Relative estimates of rainfall recharge is shown on the **1:75,000 Hydrogeology Map**. Higher recharge is estimated within the sandy soils in the lower eastern catchment and in the mid and lower broad alluvial drainage valleys. The eastern flanks of ridges and drainage lines are likely to have greater recharge potential due to sandy material in these regions. Water chemistry confirms high recharge and salt flushing in these regions.

Waterlogging and inundation within the central drainage lines and flats would also contribute significantly to recharge. Extended periods of waterlogging allow the soil profile to become saturated, even within clayey and heavy soils. Soils in the vicinity of the lakes would also contribute to recharge. Eventually as the water table rises, the low lying valley floors will become recharge discharge features. It has been estimated that up to 10% of rainfall infiltrates in these areas, locally it may be greater, especially in the more sandy regions to the south east.

Recharge to the mid to upper catchment through the saprolite and lateritic profiles is considered to be up to 8%. Localised increases in recharge will occur around granitic monodochs and duplex soils.

Recharge to the groundwater system in vegetated regions is considered to be 0 to 3% of rainfall owing to plant uptake.

The recharge values reported are weighted average values. Recharge to the groundwater system is considered to be relatively low during average rainfall years. The majority of recharge will occur during episodic events. Lewis (1996) indicated that episodic recharge can make up a large proportion of total recharge. All aquifers will respond differently to episodic events. Some may not respond at all, others, particularly in the lower catchment where infiltration is greater and where waterlogging occurs for extended periods, will respond rapidly. Hydrographs for LB19 shows a rapid response to an episodic event during 1998.

5.10.2 Aquifer Flow and Discharge

The rate of water table rise across the entire catchment will be proportional to the volume of water that can be transmitted through the aquifer. The contour map shows groundwater is flowing downslope towards the lower catchment. Prior to clearing, groundwater recharge was likely to be less than present, and the aquifer system would have been able to transmit the flow of groundwater through the valley floor. With clearing recharge to all aquifers has increased and the low hydraulic gradients within the valley floors and topographic low points will be insufficient to transmit the recharged groundwater. As a result the water table has risen.

The groundwater system within the catchment is responding to increased recharge. The surficial aquifer in the lower catchment has responded dominantly to recharge due to waterlogging and the presence of sandy sediments along the fringes. Water levels are rising and are close to the surface in the valley floors.

The Tertiary palaeochannel aquifer is not monitored, however it is likely to have a confined response with an increase in piezometric pressures. As the hydraulic head within the surrounding catchment increases, so will the piezometric pressure within the palaeochannels. This saprolite aquifer is currently responding slowly to recharge due to low permeability layers and changes in the overall water balance. This aquifer will also continue to rise increasing the hydraulic head and driving the groundwater to flow into the lower catchment surficial and Tertiary aquifers.

Discharge can also occur where faults, shallow basement or dykes transect the groundwater flow direction. Essentially, these structures result in a reduction in transmissivity. South of Lake Bryde, towards Ryans Road, water logging and salinity appear to be associated with dykes and Ryans and Lockhart Faults. It is likely that there has been a restriction in groundwater throughflow in this area, resulting in a rise in groundwater levels. Waterlogging is extensive in this region and likely to be contributing significantly to recharge. This area appears to be both a recharge and discharge zone.

Other forms of discharge occur as sandplain seepage in the lower south eastern catchment. Shallow basement and iron stone have also resulted in seasonal discharge in the mid and lower slopes to the west of lake Bryde.

In general the catchment water balance has been disrupted from additional recharge, resulting in a rise in groundwater levels. The groundwater is still responding to the increased recharge. Eventually, under current recharge conditions, the water balance will approach steady state. To predict the steady state water levels, groundwater modelling can be used.

6. Extent of Salinity

The current area of salinity impact is shown on the **1:75,000 Hydrogeological Map**. At present the areas impacted by salinity are located along the western fringe of the broad valley floors. Other areas of impact include South Lake Bryde sub-catchment, which has developed extensive salinity from waterlogging and poor surface water drainage.

6.1 Current Problem

Groundwater levels are rising, however, presently the dominant salinity problem in the catchment is secondary enrichment of surface waters. These waters are evaporating on waterlogged land and discharging to lakes, causing deterioration of both the water and soil quality. Presently water runoff from the entire catchment is contributing to the problem. The western margins of the valley floors have deteriorated initially primarily due to greater volumes of runoff entering these areas and extended periods of waterlogging.

6.2 Predicted Problem

With continued recharge, groundwater will continue to rise. Piezometric pressures have already developed within the lower catchment since clearing. In some areas of the valley floor groundwater discharge and salinity is already occurring. The rise in groundwater levels will eventually cause groundwater discharge over a wider area of land and at increasing elevation.

Once groundwater levels intersect the base of lakes, saline water discharge will occur, resulting in the deterioration of the lakes. Some lakes have already suffered groundwater discharge. Whilst the piezometric pressures are relatively low at the base of the lakes, a hydraulic head resulting from a fresh water body in the lakes will retard the vertical leakage. Ultimately, as the piezometric pressures increase and the discharge of salt from capillary rise is far greater than fresh water influx and hydraulic head, the lake will become saline and deteriorate.

6.3 Deterioration of Lakes and Wetlands

Firstly, wetlands and lakes along the western side of the broad valley floors will continue to deteriorate as saline surface water runoff discharges into these low lying and hydraulically interconnected features. Groundwater discharge is also occurring in these zones and the area of impact will gradually encroach to the east.

Simultaneously, ephemeral shallow lakes will experience the discharge of shallow saline groundwater. These lakes are typically internally drained, vegetated and located south of Newdegate Pingrup Road and fourteen mile road intersection.

East Lake Bryde is showing early signs of groundwater discharge with brackish water and vegetation stress. Given the surrounding environment is sandplains, this lake should be relatively fresh, however with increasing groundwater levels the salinities will rise. Similar lakes further south in vegetated sand plain areas remain fresh due to lower groundwater elevations. The lake located approximately 1km north of Lake Bryde appears to have been impacted from a combination of surface water runoff and groundwater discharge.

The larger perennial lakes, including Lake Bryde will increasingly become more saline and deteriorate as groundwater discharge and capillary rise deposit salts into the basal sediments. Groundwater is close to the base of Lake Bryde and water chemistry results indicate that some groundwater discharge may already be occurring.

As the topography of the valley floors is relatively flat, impacts will probably occur in relatively quick succession. Secondary enriched saline runoff will also continue to increase the salt load of the lakes during peak and average runoff periods.

7. Groundwater Modelling

7.1 Introduction

Groundwater modelling was completed for the entire study catchment to simulate the rise in water table and identification of salinity risk areas. Outputs from the model identify groundwater depths for current and various time steps. The modelling outputs are indicative estimates only of temporal and spatial groundwater levels.

The model was developed from the conceptual hydrogeological model identified from drilling and field mapping, including relative areas of recharge, hydraulic conductivities, aquifer geometry and water levels. Calibration of the model was then completed using available monitoring data for the South Lake Bryde Sub-Catchment.

Risk Identification

The calibrated model was run to simulate the rise in groundwater levels for 2, 5, 10 and 20 year time-steps. The risk modelling identified:

- Depths to groundwater and area of impact for various time steps; and
- Potential impacts to vegetation associations found below the 300m contour.

Treatment Modelling

Various treatment scenarios were run to simulate groundwater response to recharge reduction. The treatment methods included:

- Recharge reduction for the entire catchment; and
- Higher recharge and increase in size of cleared areas.

Treatment methods assume recharge is reduced by any method and does not consider specific options such as the efficacy of deep perennials over surface water management.

The model does not consider salinity and waterlogging risk areas from secondary enriched surface water runoff and therefore is not able to accurately reflect all salinity risk areas. Surface water modelling or hybrid surface/groundwater models would need to be completed to obtain a complete understanding of risks.

7.2 Data Collection and Analysis

7.2.1 Introduction

The majority of the data used in this study has been supplied by the Department of Conservation and Land Management (CALM) and sourced from other government agencies including:

- Agriculture Western Australia (AGWEST);
- Water and Rivers Commission (WRC);
- Land Monitor Project; and
- Bureau of Meteorology.

7.2.2 Topographic Data

A digital elevation model (DEM) was used to represent the surface topography in the model. This information was supplied in digital form by CALM. The DEM is generated from 10 m spot height elevations in the x and y direction and is accurate to ±1.5m. **Figures 7.1** and **7.2** illustrates the surface topography generated from the DEM for the Lake Bryde catchment.

Figures 7.1 and 7.2 clearly illustrates the valley flats through the centre of the catchment.

7.2.3 Rainfall and Evaporation

Rainfall and evaporation will be the dominant variables driving the groundwater flow system in the catchment. Monthly rainfall and pan evaporation totals were obtained from the Bureau of Meteorology. Rainfall totals were obtained for the Newdegate and Pingrup stations. The two data sets are in general agreement except for a significantly higher rainfall total recorded at Newdegate on Feb 1998 and Jan 2000. **Table 7.1** summarises monthly rainfall averages at the two stations including and excluding these two rainfall events.

Table 7.1: Rainfall Summary

	Newdegate	Pingrup
Including High Rainfall Events		
Mean Monthly	30.0mm	27.2mm
Std Deviation	30.6mm	23.4mm
Excluding High Rainfall Events		
Mean Monthly	26.5mm	25.9mm
Std Deviation	22.4mm	21.9mm

The Pingrup data set was adopted for the modelling as it was a more complete data set over the calibration period.

The closest stations to the study area at which evaporation data was available were Narrogin and Corrigin. However, data from the Narrogin station was limited to between 1971 and 1984. Data was available from the Corrigin station over the period 1988 to 2000. Therefore there was no overlapping period over which the evaporation rates for the two stations could be compared. Mean daily averages were constructed for the two stations over the respective periods. Evaporation at the Narrogin station was approximately 10% less than at Corrigin. Therefore for modelling, evaporation data from the Corrigin station reduced by 10% was adopted.

Figure 7.1: Lake Bryde catchment contour map based on 2 m DEM

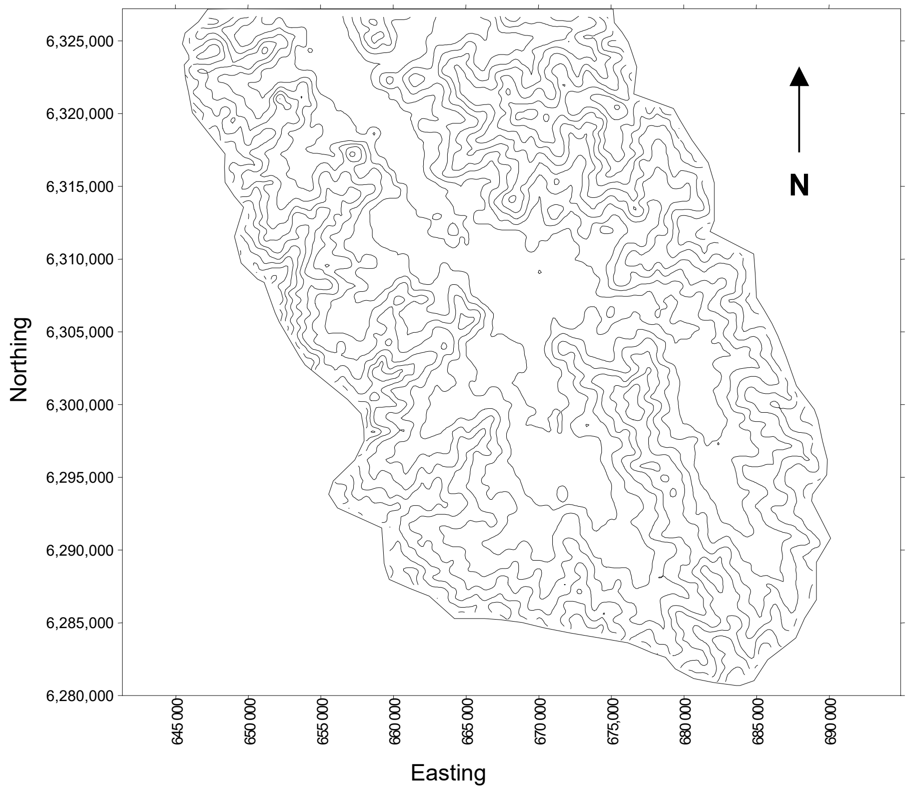
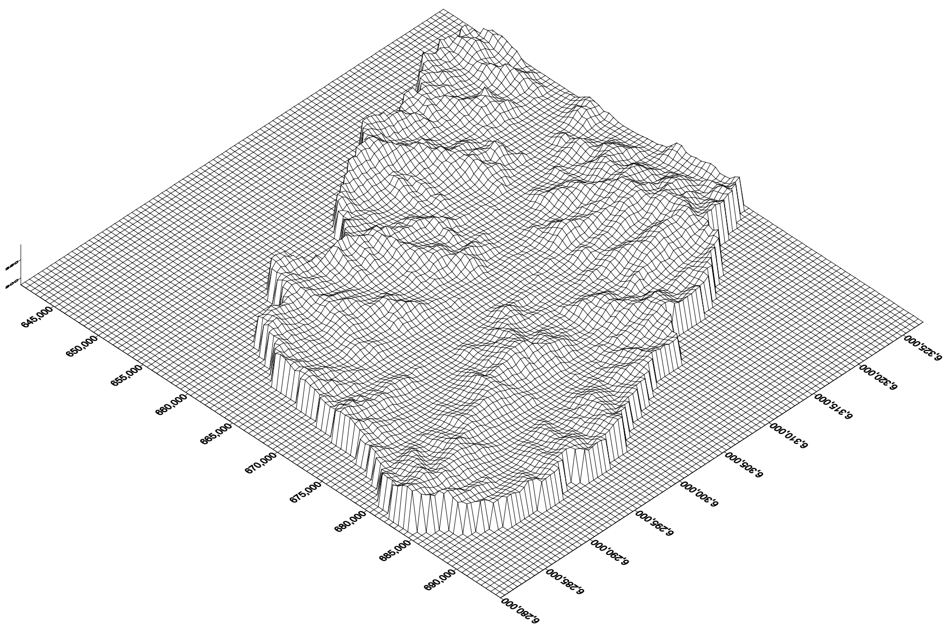


Figure 7.2: Lake Bryde Catchment topography – surface model



7.2.4 Head Observation Wells

Details of observation bores and records were obtained from CALM and AGWEST. A summary of piezometer and groundwater level information is shown in **Section 5.3**.

7.3 Model Construction

7.3.1 Description of Numerical Model

A groundwater model was constructed to simulate observed rising water levels in the Lake Bryde catchment and to identify areas in the catchment which are under risk from salinity. Numerical simulations were carried out using the internationally recognised finite difference groundwater model USGS MODFLOW. The model construction, execution and post processing was done using Visual MODFLOW Version 2.8.2. MODFLOW was selected due to its wide usage and simplicity in construction.

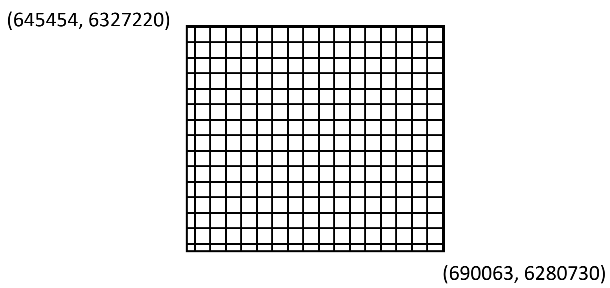
7.3.2 Conceptual Model

The model domain consisted of a region 44.6km by 46.5km. The model was discretised as a one layer model using 250 columns and 250 rows. The layer thickness was kept uniform at 40m over the whole model domain. This aquifer represented the saprolite system, with the overlying alluvial system in the low lying areas modelled as a higher conductivity zone.

7.3.3 Model Development

Grid Design

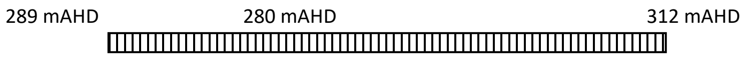
The extent of the model domain is illustrated below. Cell sizes were of the order of 180m both in the x and y directions. A uniform grid with no grid refinement was adopted over the model domain.



Boundaries

The catchment boundary was set as a no flow boundary with all cells outside the catchment boundary rendered inactive.

A general head boundary (GHB) was set along the northern boundary as a means of allowing flow out of the catchment. A linearly varying head was set for the boundary based on initial heads at the boundary. Heads varied linearly according to the relationship below.



The simulation period was divided into monthly stress periods.

Initial Heads

Initial groundwater hydraulic heads used for the model were those recorded on the 22/4/96 (**Table 7.2**).

Table 7.2: Initial hydraulic heads

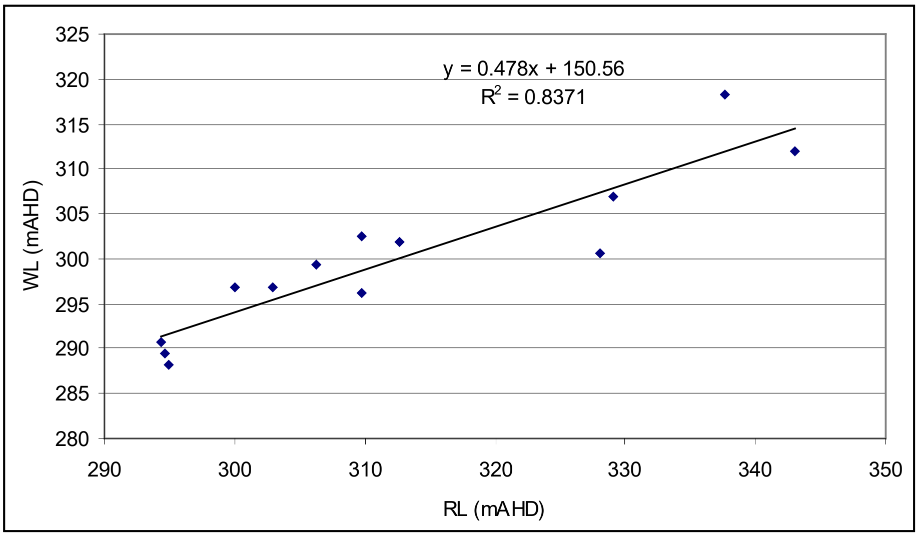
Bore ID	Easting	Northing	WL (mAHD)
LB6	664678	6299387	312.27
LB5	664655	6299399	313.04
LB2	667662	6303074	299.26
LB3	667486	6303093	299.43
LB07d	666967	6301981	299.30
LB08d	671869	6296158	296.81
LB09d	670657	6298615	296.85
LB10i	674863	6292206	296.20
LB11	678010	6292180	300.65
LB12	669307	6291872	301.79
LB13	669342	6288237	284.69
LB14	661622	6290771	311.95
LB15	659125	6295649	318.36
LB16	665118	6295067	307.02
LB17d	668397	6295511	302.40
LB18	669732	6308561	288.13
LB19	670212	6308585	290.65
LB20	670139	6307958	289.55

The initial water table contour for the region of available information is given in **Figure 7.4**.

The above information then needed to be extrapolated to the remainder of the catchment to establish a set of initial heads for the modelling domain. This however presented problems as the extrapolation procedure indicated that heads in the palaeochannel drainage north of Lake Bryde were above ground level. A relationship was therefore established between natural surface level (NSL) and the water level (WL) to simulate initial heads in the northern part of the catchment. **Figure 7.3** presents a linear relationship between NSL (mAHD) and WL (mAHD) in bores with records at the start of the calibration period.

This relationship was used to establish a set of “dummy initial heads” in the northern part of the catchment.

Figure 7.3: Relationship between WL and NSL



As observation bore records in the East Lake Bryde Sub-Catchment used to contour initial heads were not complete, the resultant contour indicated that heads were falling towards the eastern catchment boundary. This problem was corrected by establishing the average increase in groundwater level in bores which have been monitored over the full calibration period. This average rate of rise was then used to establish a set of initial heads for the East Lake Bryde Sub-Catchment.

The resultant initial head contour used for modelling is presented in **Figure 7.5**.

Aquifer Properties

Initial aquifer properties were based on results obtained from the field investigation. Two conductivity zones were represented in the model, one for the saprolite and another for the overlying alluvial system occurring through the palaeodrainage system. The initial hydraulic conductivity for the two zones were averages of tests conducted in a number of bores and is presented in **Table 7.3**. Vertical conductivities were approximated to be one tenth of the horizontal conductivity.

Figure 7.4: Initial head contour

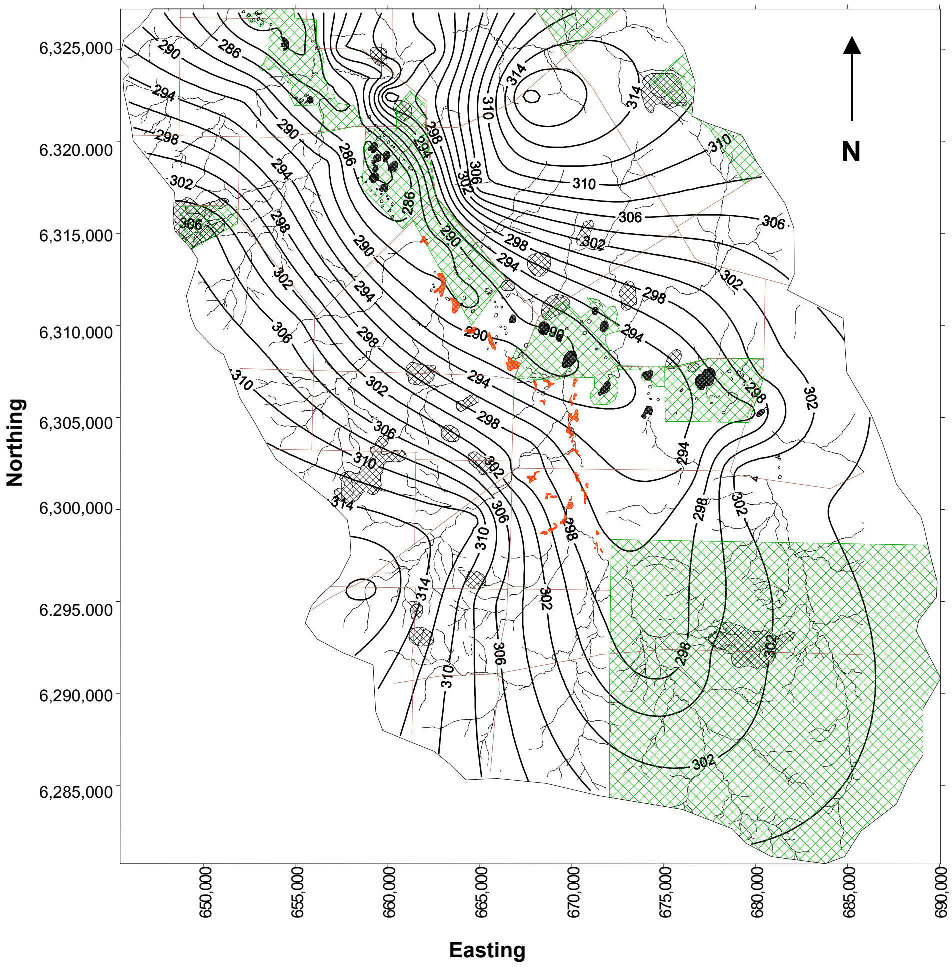


Table 7.3: Adopted Aquifer Hydraulic Conductivities for Modelling

Aquifer	Kx = Ky (m/day)	Kz (m/day)
Alluvial	0.413	0.0413
Saprolite	0.014	0.0014

The distribution of hydraulic conductivity across the model domain was refined during the calibration phase and will be largely based on the location of the palaeodrainage system.

Recharge
The recharge rate was determined through calibration as a fixed fraction of rainfall and was specified as a time varying rate for four type areas (see **section 7.4.1** below).

Evapotranspiration
Evapotranspiration was also specified as a time varying rate. The evapotranspiration is assumed to be a linear function of water table depth, and is equal to zero at a specified extinction depth. The extinction depth is influenced by the level of remnant vegetation in the catchment and was determined through calibration to reproduce observed groundwater hydrographs.

7.4 Model Calibration

Model calibration involves setting stress conditions that are consistent with historical observations over a period in which the groundwater response has been recorded. Variables within the model are then iteratively refined in an effort to adequately reproduce the observed groundwater response.

The calibration period was between April 1996 and May 2000. The only stresses which have been imposed on the model are the effects of recharge and evapotranspiration.

The quality of the calibration will be evaluated in terms of the root mean square of the deviations for each observation point.

7.4.1 Calibrated Parameters
The final calibrated hydraulic and stress properties are described below.

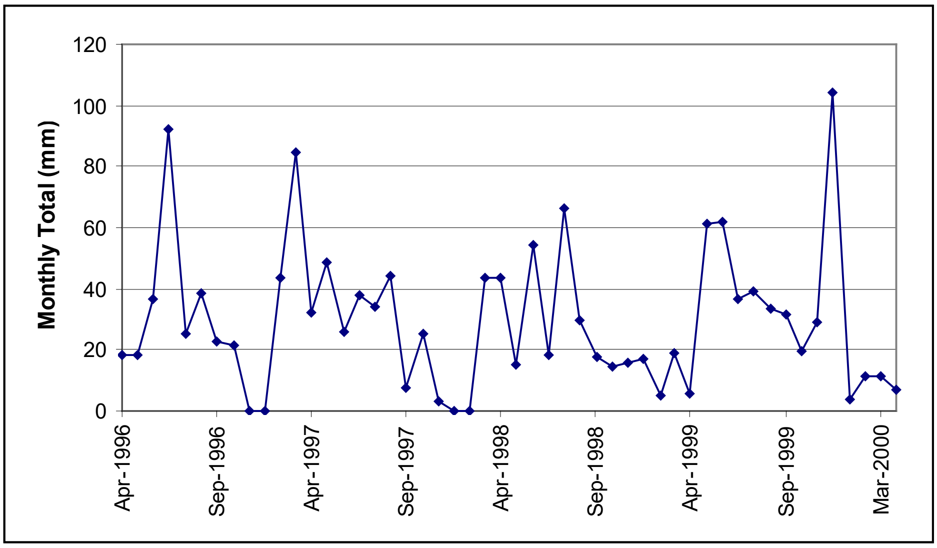
Hydraulic Conductivity
Hydraulic properties were the same as that initially used during model set up. That is 0.413 m/day for the alluvial and 0.014 m/day for the saprolite aquifers. The two zones of hydraulic conductivity was spatially distributed based on the location of the palaeodrainage system. The spatial distribution of hydraulic conductivity used in the model is shown in **Appendix D**.

A specific yield of 0.1 was used uniformly across the model domain. The model was found to be unstable when values lower than this was used.

Recharge
Recharge was taken to be a fixed percentage of rainfall, with four different recharge time series being used over the model domain. These were:
1. Woody vegetated areas – 3% of rainfall;
2. Palaeodrainage channel and lakes – 10% of rainfall;
3. Surrounding catchment – 8% of rainfall; and
4. Shallow bedrock features – 0% of rainfall.

Figure 7.5 illustrates the rainfall time series over the calibration period. Recharge was taken to be a fixed fraction of this as explained above.

Figure 7.5: Rainfall time series



The spatial distribution of the recharge time series is presented in **Appendix D**.

Evapotranspiration (ET)

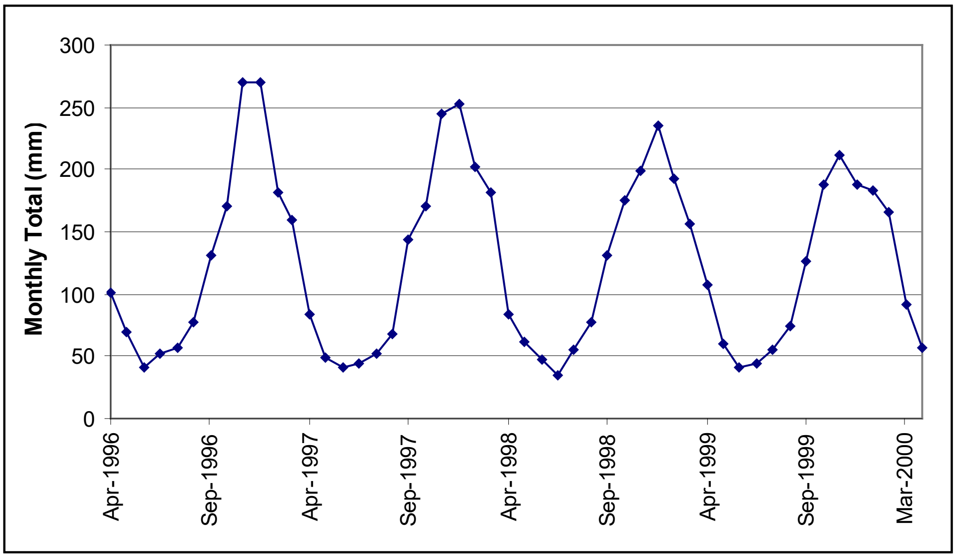
Evaporation rates were also set at a time varying rate proportional to recorded pan evaporation levels which were adjusted accordingly to represent evapotranspiration. Three different evapotranspiration time series were used in the model.

1. Woody vegetated areas – ET depth of 1.5m;
2. Lakes – ET depth of 1.0m; and
3. Surrounding catchment – ET depth of 1.0m.

The evapotranspiration intensity was kept uniform across the whole catchment. **Figure 7.6** illustrates the evapotranspiration time series used in the model. The spatial distribution of evapotranspiration is presented in **Appendix D**.

The effects of evapotranspiration will be negligible at this stage in catchment history as water levels are yet to reach 1.0 to 1.5m below ground level, at which time evapotranspiration is activated.

Figure 7.6: Evapotranspiration time series



Boundaries

No flow boundaries were assigned around the catchment boundary with a general head boundary at the northern catchment boundary. The head for the boundary was varied linearly according to initial heads and was assigned a conductance of 10m^2/day.

7.4.2 Calibrated Hydraulic Heads

The calibrated model heads and observed heads for the monitoring bores are presented in **Appendix E**. **Figure 7.7** illustrates a water table contour map at the end of the calibration period.

A velocity vector plot illustrating relative groundwater flow magnitude and direction is presented in **Figure 7.8**.

Despite the possibilities for error using a 180 m grid spacing and the simplicity of a one layer model, the general agreement between observed and modelled hydrographs is good. The predicted heads illustrates the steady rate of rise in water levels being experienced in the majority of the observation bores.

Figure 7.7: Water table contour at end of calibration period

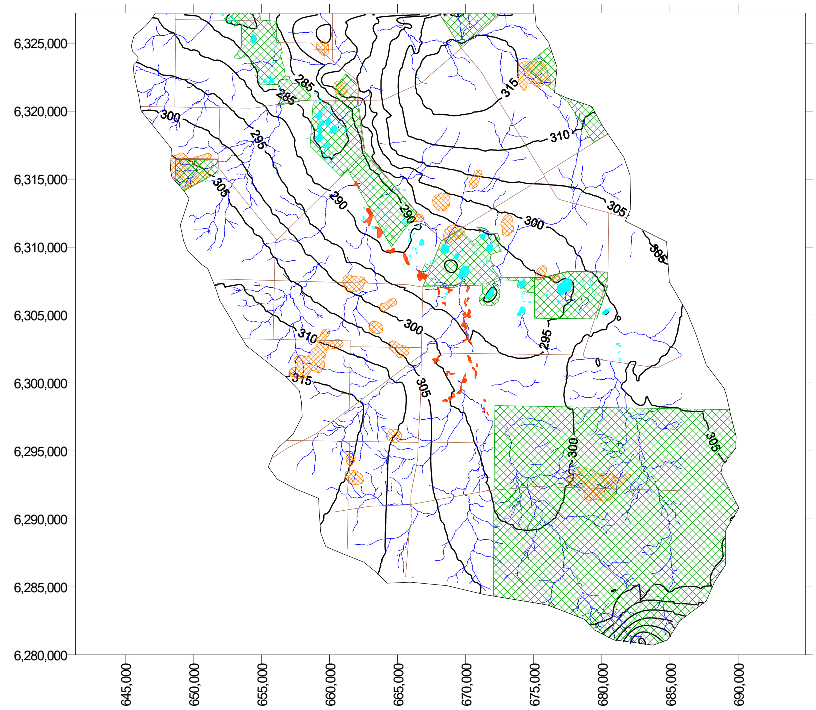
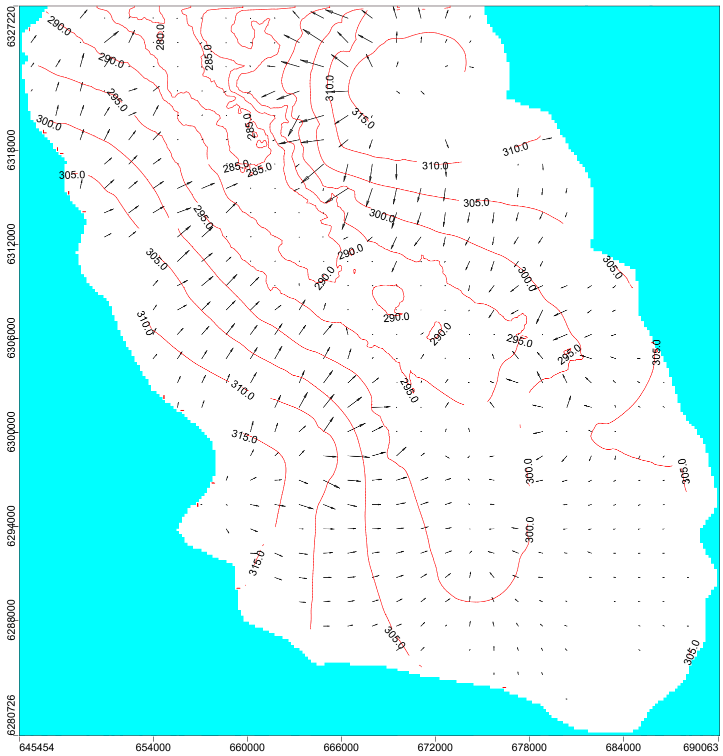


Figure 7.8: Velocity vector plot



Modelled heads from Bore LB10 do not rise as steeply as observed in the field. This bore is located within the Lake Magenta Nature Reserve which has been assigned a lower recharge rate of 3% of rainfall. It is likely that this bore is experiencing higher rates of recharge through localised effects which are causing water levels to rise at a steeper rate. Bore LB11 is also within the Lake Magenta Nature Reserve. This bore however shows a general decline in water levels. The modelled heads are steady with a gradual decrease as the zone surrounding this bore has been assigned a recharge rate of 3% to reflect the shallow bedrock found in the vicinity of the bore.

Modelled heads for Bore LB3 indicate a faster rate of rise than that observed. In reality, bores LB2 and LB3 should be responding similarly as they are within 200m of one another. Localised effects are therefore again likely to be controlling water levels in LB3 to keep water levels fairly steady over the calibration period. Bore LB2 however shows good agreement between observed and modelled heads.

There also exists a significant difference between modelled and observed heads in Bore LB19 located in the north east corner of Lake Bryde. Observed heads in this bore rise much faster than that in bores LB18 and LB20. Note that bores LB18 and LB20 which are also located around Lake Bryde show good agreement between modelled and observed heads.

Figure 7.9 presents modelled and observed heads at the end of the calibration period.

RMS Error

The calibration match between observed and modelled heads can be quantified statistically in terms of the root mean square of the variations between the observed and calculated groundwater hydrographs. A plot of root mean square deviations against model time is presented in **Figure 7.10**. The figure also presents the error during model time excluding bores LB10, LB11, LB3 and LB19.

Including all bores, an average root mean square error of 0.68m (range of 0.45 to 0.9m) was achieved over the calibration period. This average reduces to 0.52m (range of 0.3 to 0.8) when the effects of a number of spurious bores are excluded.

Figure 7.9: Modelled vs observed heads @ t = 1501 days

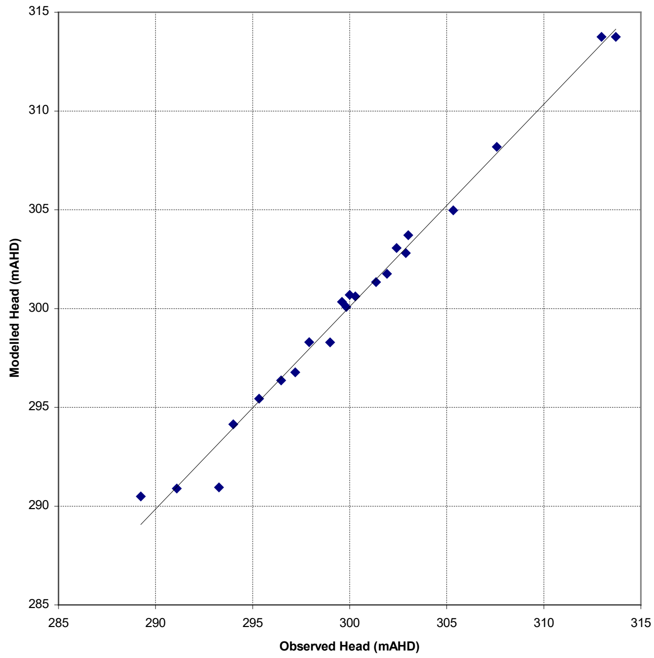
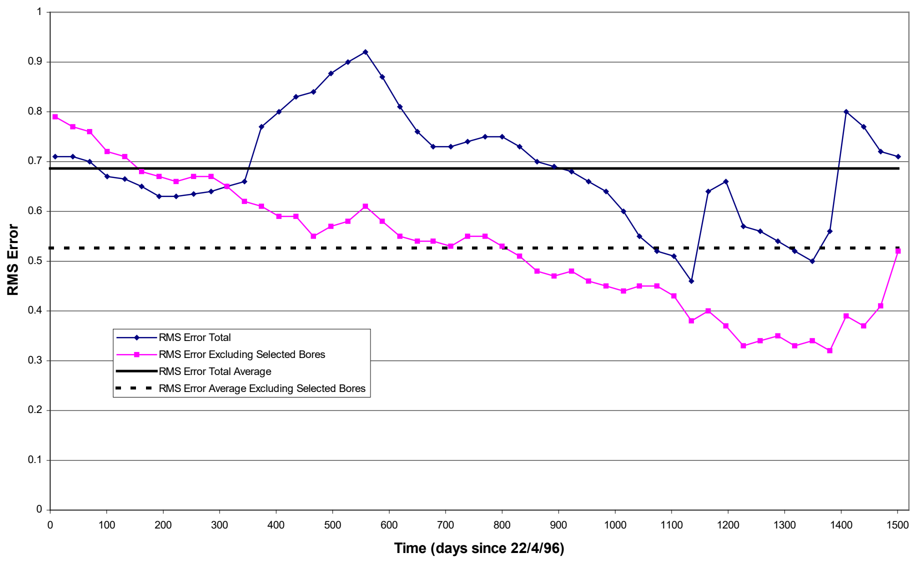


Figure 7.10: RMS calibration error against model time



7.5 Sensitivity Analysis

Sensitivity analysis was carried out by varying a number of model input parameters to observe the relative change in model response. These parameters were hydraulic conductivity, specific yield and recharge rates. **Table 7.4** presents a summary of the sensitivity analysis simulations conducted.

Table 7.4: Summary of sensitivity analysis simulations

Title	Description
S1	Hydraulic conductivity in all zones decreased by a factor of 5.
S2	Hydraulic conductivity in all zones increased by a factor of 5.
S3	Specific yield increased by a factor of 2
S4	Specific yield decreased by a factor of 5
S5	Recharge rates decreased by a factor of 2
S6	Recharge rates increased by a factor of 2

Changes in hydraulic conductivity in runs S1 and S2 did not result in significant variations in the modelled heads. Increasing the conductivity by a factor of 5 contributed to water levels rising faster in a number of bores including UB3, UB2, UB1, LBE2, LB5, LB6 and LB10. Heads in bore LB11 decreased and matched more closely with observed heads suggesting that the area surrounding this bore may be a higher conductive zone. The model response was similar to a decrease in the conductivity by a factor of 5, with the exception of bore LB11 which remained fairly constant.

The model response was again relatively insensitive to an increase in the specific yield by a factor of 2 (S3). It contributed to heads in bores UB1, UB2, UB3, LBE2, LB5 and LB6 rising at a slightly faster rate. A decrease in the specific yield by a factor of 5 (S4) caused an instability in the model and no output could be retrieved.

By far the strongest influence on modelled heads was run S5 which represented a decrease in the recharge rates by a factor of 2. The change contributed to a response in nearly all the observation bores, causing a lower rate of rise in water levels in comparison to observed levels. In some bores, it caused a recession of water levels before an increase occurred. This suggests that the amount of recharge is a dominant factor controlling rising water levels within the Lake Bryde catchment.

8. Salinity Risk Modelling

The calibrated groundwater model can be applied to simulate various groundwater level scenarios under existing aquifer recharge and flow conditions. The modelling is broad scale and does not represent localised variations or surface water interaction. However, the model enables an assessment of spatial and temporal response of the system to:

- Various recharge controls within the catchment, completed as part of management and treatment options; and
- Groundwater pumping within the lower catchment.

8.1 Predictive Simulations – Existing Recharge/Flow Conditions

A number of predictive simulations were carried out to identify areas within the catchment under threat from salinity directly as a result of rising groundwater levels. These predictive simulations were based on average rates of rainfall and evapotranspiration.

Predictive simulations were run for present conditions, 5, 10 and 20 years. **Figures 8.1** to **8.4** illustrate risk areas within the catchment at present and for the above mentioned simulation periods. These risk areas have been categorised in terms of the water level metres below ground level (mbgl) between the following intervals. Note that identified risk areas are purely based on rising groundwater levels within the catchment:

- > 0.0m (ie groundwater discharge);
- 0.0 - 0.5 mbgl;
- 0.5 - 1.0 mbgl;
- 1.0 - 2.0 mbgl; and
- 2.0 - 5.0 mbgl.

Under current recharge conditions it is estimated that the salinity of groundwater will increase with time. **Figure 8.5** identifies the extent of the catchment where groundwater levels are <1m for various time steps. It also identifies the vegetation communities below the 300m contour, which may be at risk from these predicted groundwater levels.

Persistence of the present conditions will ultimately result in large tracts of the East Lake Bryde Sub-Catchment, South Lake Bryde Sub-Catchment, Lake Bryde Reserve Sub-Catchment and the Lakelands Sub-Catchment experiencing groundwater levels at 2m or less below surface.

The area of groundwater rise and impact is proportional to topographic elevation.

A summary of temporal and spatial impacts under current aquifer recharge, throughflow and storage includes:

- Currently, groundwater is typically greater than 1 metre below ground level within the broad valley floors. In the low-lying area, the levels have been predicted to be less than 1m below ground level, covering an area <1% of the entire valley floor. The major areas of impact include the base of the lakes.

- 5 years – Surficial groundwater levels are predicted to rise with approximately 2-5% of land beneath the 300m contour having groundwater levels <1m, dominantly beneath lakes and in the low lying wetlands. Groundwater is predicted to be between 1 and 3m beneath most of the valley floor areas. Some groundwater discharge will be occurring within most lakes. The volume of groundwater discharge into lakes will depend upon the elevation of the lake base, volume and period of water storage and the permeability of the basal clays.

- 10 years – Surficial groundwater levels will be <2m beneath the majority of valley floors and <1m beneath 35-40% of the valley floor and surrounding secondary drainage channels. The majority of lakes will have shallow saline groundwater discharge as base surge. Groundwater expressions, as waterlogging will impact over 15% of the low-lying areas. Large extents of vegetation communities beneath the 300m contour will be impacted.

- 20 years – Groundwater levels will continue to rise and discharge at the ground surface over the majority of the low-lying areas around the entire catchment. All of the lakes and wetlands will suffer groundwater discharge.

Figure 8.6 illustrates the vegetation ecosystems (Mattiske, 1998) below the 300 m contour at risk from rising groundwater. This figure indicates that a lake directly to the north west of Lake Bryde will have groundwater levels >1m below ground level during the modelled period due to the floor of the lake being elevated in relation to the surrounding ground level. Eventually, however, this lake may still become impacted from rising groundwater.

8.1.1 Model Limitations

It is important to recognise that this is a modelled simulation and that variations in the actual conditions are likely to occur. For example, the 10 and 20 year model simulations represent groundwater discharge along superficial and saprolite aquifer boundaries, however the actual extent of discharge may be closer to the valley floors. This is a function of the model definition and scale. Higher hydraulic conductivities are likely to exist at the interface between the superficial and saprolite aquifer resulting in greater throughflow in these areas and less groundwater discharge during this time step. The model would need to be redefined to a smaller scale to represent these types of discontinuities in aquifer characteristics. This factor demonstrates the limitations of a groundwater model at this scale and definition for determination of specific changes in specific areas, but is useful in determining broader scale changes for the purpose of initial predictions.

It is also important to keep predictive simulations in context of the period of available information used to construct the groundwater model. The groundwater model was calibrated between 1996 and 2000. We have found from the model that the dominant groundwater process contributing to rising water levels in the catchment is recharge.

8.2 Predictive Simulations - Recharge Reduction

A number of recharge reduction scenarios were simulated to assess the effect on groundwater levels in the catchment. These scenarios represent a total reduction in recharge through any methods whether it be:

- Revegetation with deep rooted perennials to reduce recharge of surface water to the aquifer; or
- Surface water management to reduce waterlogging and consequently recharge.

Groundwater pumping as a management option has been modelled separately.

The scenarios modelled included:

1. A 50% reduction in recharge across the catchment - simulated by a 50% reduction in all recharge zones, including vegetated areas – **Figure 8.7**.
2. Recharge reduction of a strip west and south of the Lake Bryde Reserve - simulated by reducing recharge to 3% of rainfall. Higher groundwater recharge is considered to occur in these regions at present – **Figure 8.8**.
3. Recharge reduction of the whole catchment - simulated by reducing recharge to 3% across the whole catchment – **Figure 8.9**.
4. Recharge reduction of the East Lake Bryde and South Lake Bryde sub-catchments - simulated by reducing recharge to 5% as it would be difficult to achieve a reduction in recharge to 3%. Note that the recharge within the Lake Magenta Nature Reserve was kept at 3% – **Figure 8.10**.

These scenarios will allow each of the above management options to be broadly assessed and compared.

Figures 8.11 and **8.12** present a summary of the reduction in area (km^2) over various water level intervals (mAHD) after 1,500 days and 20 years respectively. **Table 8.1** below tabulates this data for the 20 year simulation.

Table 8.1: Recharge reduction effects – 20 years

Scenario	< 280m	< 285m	< 290m	< 295m	< 300m
Present situation	2.6	40.3	124.0	315.4	577.4
100% Recharge reduction	8.0	22.9	79.5	181.8	386.8
50% recharge reduction	8.3	27.4	76.7	165.5	370.0
Recharge reduction in East and South Lake Bryde sub-catchments	7.4	22.4	69.3	143.2	296.1
Recharge reduction in Lakeland sub-catchment	7.4	22.4	69.2	140.1	256.8
No change to recharge	7.3	22.4	68.7	135.8	247.6

Table 8.1 above presents the catchment area within each topographic interval. For example, for the no intervention case, in 20 years, only 245 km^2 of the catchment has its water level below 300mAHD, and if you achieve a 50% recharge reduction across the whole catchment, this area would rise to 370 km^2.

Figure 8.13 presents the percentage of the catchment with water level within 1 m below ground level with time. For example in 20 years, for the no intervention case, almost 20% of the catchment has a water level within 1m of ground level, but with 100% recharge reduction, this reduces to only 10% of the catchment.

8.2.1 Interpretation of Results

Modelling results indicate that all of the treatment options will reduce the area impacted by rising groundwater levels, particularly within the valley floors.

A 100% reduction of recharge results in the most favourable treatment methods. Recharge reduction in the South Lake Bryde and East Lake Bryde sub-catchments and a 50% reduction in recharge over the entire Lake Bryde catchment are the second most effective treatment methods.

However, these results indicate that recharge reduction alone within the next 20 years (and potentially more) will not reduce groundwater levels within the lower catchment quickly enough to prevent overall water level rise. Elevated piezometric pressures from semi-confining conditions and a reduced aquifer storage capacity will ensure groundwater levels remain elevated.

The majority of the lakes and ecosystems within the valley floors will deteriorate before recharge reduction options sufficiently lower piezometric pressures and groundwater levels. Therefore, it is likely that this treatment would need to be applied with alternative groundwater reduction techniques.

8.2.2 Groundwater Pumping/Drainage

Groundwater pumping around Lake Bryde was investigated as a remedial option for lowering groundwater levels in the vicinity of the lake. The simulated option consisted of a set of 3 pumping bores, each pumping at a rate of 3L/s. A higher conductivity zone (K_x = 1m/day) was assigned for the region surrounding the lake to better represent the highly permeable formation. This was higher than the average conductivity assigned for the alluvial formation as a whole.

Figure 8.14 illustrate the effects of this management option. The plots present water table contours for a five year simulation, with and without the effects of pumping. **Figure 8.7** clearly represents the decrease in water levels around Lake Bryde.

Groundwater pumping from three production bores around Lake Bryde lowers groundwater levels within the vicinity of the lake to greater than 3m below ground level. Pumping from these bores may also reduce groundwater levels over a broader area within the broad valley floor.

The modelling assumes isotropic and homogeneous aquifer flow conditions and does not allow for discontinuities in aquifer permeability, thickness or storativity. To fully simulate specific aquifer response to groundwater pumping in a specific area, a greater understanding of aquifer characteristics and geology is required.

However, the model does identify that groundwater pumping may be an option to reduce elevated piezometric pressures within the Tertiary aquifers and water levels within the overlying surficial aquifers in specific areas. ie. Broad scale pumping would be prohibitive but specific areas could be protected through installation of pumping bores around targeted features to be protected.

9. Summary and Management Options

9.1 Surface Water Control

The dominant salinity problem currently facing the Lake Bryde Catchment is the discharge of enriched surface water. The impacts will depend upon surface water runoff volumes and salt loads. In addition, as the lakes in the catchment are morphologically variable they will respond differently to various runoff scenarios. The salt loads and water levels will change under various hydrological conditions. Salt loads may be flushed from the lakes under episodic or above average rainfall conditions.

Both biological and engineering options are available to control surface water and recharge. This report does not specifically address revegetation other than considering it as a part of recharge reduction. However, it is recognised as an important issue which should be considered as part of integrated catchment management.

If surface water runoff is to be controlled via engineering options, a number of issues will need to be considered.

- Application of surface water and groundwater control through drainage;
- Seasonal diversionary features to existing wetland and lake systems; and
- A disposal option and environmental impacts will also need to be identified.

Drainage

Firstly, it is anticipated that surface water from the surrounding slopes would need to be collected through contouring and shallow drainage. These smaller farm scale systems would need to discharge into larger drains, which transfer the water to a disposal point. Alternatively, collected fresh water could be stored for stock watering in dams.

Lake Levels

Secondly, the lakes and dependant ecosystems will require periodic inflow. The inflow volume and salt loads will depend upon the morphology and hydrology of the system. Therefore any drainage system would need to consider individual lakes or lake systems.

Under average rainfall events, water and salinity levels will vary within lakes to the east. Alternatively, under episodic events salt loads may be flushed from these lakes.

Other internal drainage lakes, typically playas, will not respond to average rainfall and episodic events will be required to fill and potentially flush the lakes.

Surface water modelling is required to define the flow scenarios under different runoff conditions. Salt load modelling can also be applied to these models.

From existing groundwater based on a general modelling results and understanding of the hydrology, a drain would be most effective along the western boundary of the valley floor.

9.2 Groundwater Pumping

Groundwater levels are rising and will eventually (within the next 5 years) intersect the base of most lakes. Groundwater pumping would be an option to lower groundwater levels and piezometric pressures locally. The area of influence will be proportional to the aquifer characteristics and the pumping configuration. A disposal option would be required.

Even though the modelling has addressed groundwater pumping on a localised scale, pumping may also be applicable to control regional groundwater levels within the valley floor.

Localised or more regional groundwater pumping, completed in conjunction with recharge reduction, may provide a more rapid and long term solution to the protection of the lake systems and sustainable agriculture. Up to 3 bores pumping at low flows, say 3 L/s each may be effective in lowering groundwater levels below the base of individual targeted lakes.

9.3 Disposal Options

Disposal of drainage water may include:

- Disposal to a sacrifical wetlands/evaporation basin;
- Building and disposal to a designed evaporation basin;
- Ground reinjection; and
- Transfer water to a saline lake within another catchment, Lake Grace.

Environmental impacts and a drainage study would be required over a catchment scale to define the appropriate issues and options including:

- Management guidelines;
- Environmental impacts;
- Efficacy of drainage and pumping;
- Sustainable agriculture; and
- Ultimate lake and ecosystem sustainability and recovery.

10. Conclusions

Sinclair Knight Merz has completed hydrogeological investigations for the Lake Bryde catchment for the purpose of establishing the potential impacts from salinity, particularly to the lakes and nature reserves in the valley floors.

The following major conclusions are made:

- Groundwater risk mapping and modelling indicates that groundwaters are rising and will impact upon the majority of lake and wetland systems within the lower landscape within the next 5-10 years. Vegetation and ecological communities below the 300mAHD contour will be impacted.

Process of Salinity
Lake deterioration has been observed to the south of the Lake Bryde Reserves and to the west of the Lakelands Reserve.

- At present salinity degradation is resulting from the discharge of saline enriched surface waters running from the surrounding catchment, discharging into fresh to brackish lakes.

Rising Groundwater Trends
Groundwater is rising from increased recharge. Groundwater occurs and flows within basement granites and associated weathering profile (saprolite), Tertiary sands and clays at the base of the palaeochannel deposits and clay and sand mixtures representing Quaternary sediments within low lying areas and valley floors.

- Groundwater hydrographs indicate groundwater levels are rising, bringing salts towards the surface.

Groundwater recharges via direct rainfall infiltration and leakage from underlying and overlying units. Groundwater is shown to be flowing towards the lower catchment along gentle gradients, eventually discharging out of the catchment through the palaeochannel sediments to the north.

- Under existing conditions net recharge will continue to be greater than discharge. Low aquifer transmissivities and throughflow volumes will ensures that the available storage capacity of the aquifer is reduced and groundwater levels rise towards ground level.

It is considered there is some hydraulic connectivity between aquifers.

Predictive Salinity Risks and Management
Numerous predictive and treatment scenarios were modelled to represent changes to the catchment water balance and groundwater level responses. The results must be viewed in context of model limitations.

- The water table is likely to rise relatively uniformly through the lower catchment and the spatial impact will to some degree depend upon the elevation of the land surface and base of the lakes. Some variations may occur due to localised confined conditions. The water table will rise and discharge into the lakes as base surge.

- These results indicated that even with total recharge reduction measures (equivalent to total revegetation of the catchment) elevated piezometric pressures within the lower catchment will enable groundwater to rise close to the surface within the next 5 to 10 years.

- Partial recharge reduction had little effect on reducing piezometric pressures and water levels within the lower catchment.

- Long term recharge reduction via an integrated system of revegetation and surface water drainage, may result in a reduction in groundwater recharge and potentially a reduction in piezometric pressures and water levels. However, the effects of recharge reduction alone will not occur quick enough to prevent the deterioration of the lower catchment and lakes.

Groundwater pumping from the Tertiary and Quaternary deposits was simulated within the lower catchment.

- Results indicates that water levels could be reduced locally and to some degree regionally from low volume groundwater pumping (10L/s) from three bores located around target features eg Lake Bryde.

Besides groundwater pumping, another option includes drainage of shallow groundwater and surface water diversion to reduce the salt load input to lakes and reduce recharge within the waterlogged areas. These options were not modelled due to model limitations.

- Any management option would need to be integrated with other measures such as revegetation of recharge areas and the use of perennial pastures and high water use crops.

A combination of management options is required. It is apparent that to avoid complete degradation specific lakes and wetlands will need to be identified for protection, while other areas will be sacrificed. Areas of greater environmental value need identifying and protective measures individually assessed.

Water disposal issues and options need to be explored further if any of these remedial techniques are to be considered.

Management options available will need to be considered in context of the entire catchment and integrated with any other catchment management plan. The proposed water and salinity management options and process which ultimately aim at reducing degradation of the wetlands and lakes within the valley floor are shown on **Figure 10.1**.

11. Further Investigations

11.1 Hydrology

Surface water hydrology needs to be defined for the entire catchment. This will help enable management options to be defined. Hydrology issues which need consideration include:

- Flooding;
- Salt loads;
- Flow directions and impedances; and
- Hydraulic connectivity between lakes and between the entire drainage system.

Surface water flow and quality should be monitored monthly. Shorter frequencies may be achieved by installing a monitoring station, ranging from GIS based interrogation to more sophisticated hydraulic models.

The costs of hydrology studies would range from $5,000 to $40,000. The costs will depend upon the degree of model complexity.

11.2 Hydrogeology

Additional piezometers need to be installed within the catchment to confirm the water table contour plan developed and identify water levels and the rise in water levels within the lower flats. Up to 10 piezometers are required.

The location of the piezometers are shown on **Figure 11.1**. At each site two piezometers should be installed within different boreholes 5 m to 10 m apart to define vertical gradients and anisotropy. Deep bores should be drilled to basement. The shallow bores should be drilled to 3 m below groundwater intersection. The deep piezometer should be drilled first to determine the geological and groundwater intersections.

Bores should be drilled at nominal 150 mm in order to install 50 mm class 9 PVC piezometers. Each piezometer should be screened using factory machine slotted (1 mm horizontal slots) casing across the groundwater intersection. The screened section is to be no less than 3 m in length across the target zone in the aquifer and finished with plain casing to the surface. End caps are to be placed at both ends of the piezometers. Once the piezometer has been installed into the borehole, a clean washed 1.6 to 3.2 mm gravel pack is to be placed within the borehole annulus from the base of the borehole to 1 m above the top of the screened section interval. A 1 m bentonite cement grout seal is to be placed above the gravel pack.

Once set, the remainder of the borehole can be backfilled with drill cuttings. A 1 m cement plug is to be installed at the top of each borehole along with a lockable steel protective cover. Once installed, the bore should be developed by surging and airlifting for between 1 to 2 hours, to remove any fines from the hole.

It is imperative that the geological profile is consistently logged and aquifer units identified by a hydrogeologist.

The cost for two bores at each site will range between $800 and $2,500.

A 150mm test production bore and three 50mm piezometers should also be installed in the vicinity of Lake Bryde. Aquifer testing should be completed and analysed to define groundwater characteristics. These tests will enable management options to be defined. The costs to complete this work would range from $7,000 to $25,000.

All monitoring bores should be consistently monitored. Monthly monitoring of water levels and electrical conductivity should also continue.

11.3 Geophysics

Geophysics will have an application in defining specific landforms and geological structures. The applications are outlined in **Appendix G**. Radiometrics, electro-magnetics and magnetics could be applied in the catchment for mapping purposes. Geophysics could be used to delineate:

- Recharge potential by identifying landforms, salt loads and soil types;
- Dykes and structures;
- Palaeochannel location and depth; and
- Shallow bedrock.

Geophysics should not be used in isolation and not all of the catchment may require its application. The role of geophysics will depend upon the degree and level of information required. In general, geophysics in the Lake Bryde catchment could be applied to:

1. Broad scale catchment mapping for the purpose of farm planning and recharge reduction.

2. Delineation of aquifer targets such as the sandy palaeochannel deposits through the broad valley flats.

The limiting factor for geophysics will be costs. The costs to acquire and process comprehensive geophysical data for the entire catchment would be up to $800,000. Using geophysics to define the palaeochannel and alluvial systems may cost up to $300,000. Costs will depend upon the methods utilised and the amount of processing required.

Geophysics is not recommended immediately and should be carefully considered, particularly in relation to what information is actually required.

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Appendix A - Groundwater Monitoring Data & Observed Hydrographs

Table A.1: Monitored observation bores

Date	LB07d	LB08d	LB09d	LB10I	LB11	LB12	LB16	LB17d	LB18	LB19	LB20
22/04/96	299.30	296.81	296.85	296.20	300.65	301.79	307.02	302.40	288.13	290.65	289.55
02/05/96	299.49	296.92	296.83	295.78	300.71	301.77	306.96	302.46	288.00	290.53	289.4
18/08/96	299.19	297.10	296.79			301.70	306.98	302.34	288.19	291.09	289.46
06/02/97	300.16			296.25		301.98	307.58	302.80	288.82	291.18	289.55
11/04/97	300.34			296.25		301.98	307.64	302.86	289.82	292.10	289.55
07/05/97	300.33			296.57		302.03	307.56	302.91	289.82	293.01	289.55
04/07/97	300.23			296.84		302.07	307.56	303.03	290.02	293.34	289.55
19/09/97	300.66			296.84		302.19	307.47	302.98	290.22	293.82	291.06
12/11/97	300.89			297.16		302.12	307.62	303.05	290.20	293.79	291.3
25/02/98	300.69			297.29		302.12	307.59	303.06	289.41	292.83	290.62
07/05/98	300.68			297.24		302.31	306.59	303.11	289.39	292.93	290.67
01/07/98	300.73			297.06		302.39	306.86	303.10	289.79	293.14	290.85
16/11/98	300.80	298.68	298.67	297.18	300.25	302.14	307.88	303.06	289.81	292.94	290.81
17/12/98	300.77	298.62	298.64	297.18	300.25	302.38	307.83	303.06	289.65	292.74	290.69
18/01/99	300.78	298.58	298.62	297.36	299.85	302.38	307.81	303.06	289.57	292.66	290.63
22/02/99	300.77	298.53	298.65	297.29	300.30	302.40	307.81	303.08	289.40	292.18	290.42
15/03/99	300.78	298.33	298.63	297.23	300.36	302.37	307.83	303.05	289.22	291.93	290.33
14/04/99	300.67	298.40	298.27	296.96	301.36	302.30	307.92	303.04	289.13	291.88	290.22
14/05/99	300.76	298.36	298.33	297.06	300.30	302.46	307.99	303.11	289.24	292.05	290.24
08/06/99	300.78	298.43	298.27	296.95	300.29	302.43	307.94	303.12	289.50	291.77	290.45
14/07/99	301.63	297.95	298.24	297.82	300.24	303.29	308.80	303.96	290.56	293.58	291.43
17/08/99	300.85	297.47	298.20	296.96	300.18	302.48	307.88	303.11	289.98	292.93	290.73
29/09/99	300.85	298.53	298.28	296.96	300.18	302.47	307.90	303.05	289.98	292.84	290.8
28/10/99	300.87	298.49	298.30	297.00	300.18	302.44	307.94	303.02	289.95	292.65	290.72
23/11/99	300.88	298.49	298.32	297.12	300.29	302.50	308.17	303.07	289.95	292.68	290.73
17/01/00	300.92	298.42	298.33	297.23		302.58	308.00	303.15	289.68	292.35	290.52
28/02/00		298.90	299.15	297.20		302.61	308.04	303.35	290.33	294.18	291.47
31/03/00		298.73	298.99			302.59		303.27	290.28	294.1	291.4

Table A.2: Bores monitored with data loggers

	LB6d	LB5d	LB2d	LB3d	LB6i	LB5s	LB2id
1/5/96	313.07	313.03			313.02		
1/6/96	313.03	312.97			313.02		
1/7/96	312.99	312.93			312.98		
1/8/96	312.97	312.89			312.96		
1/9/96	312.93	312.87			312.91		
1/10/96	312.88	312.85			312.89		
1/11/96	312.86	312.82			312.85		
1/12/96		312.62	299.26	299.48	312.85	312.87	299.43
1/1/97		312.63	299.22	299.40	312.85	312.87	299.34
1/2/97		312.69	299.21	299.40	312.85	312.88	299.32
1/3/97	312.82	312.64	299.26	299.46		312.89	299.42
1/4/97	312.85	312.68	299.30	299.55		312.89	299.47
1/5/97	312.88	312.70	299.48	299.66	312.95	312.94	299.61
1/6/97	312.93	312.73	299.50	299.66	313.02	312.97	299.66
1/7/97	312.79	312.58	299.45	299.56	312.95	312.97	299.67
1/8/97	312.86	312.77	299.43	299.60	313.01	313.06	299.68
1/9/97	312.86	312.79	299.46	299.64	313.01	313.11	299.68
1/10/97	312.87	312.81	299.50	299.67	313.04	313.17	299.71
1/11/97	312.87	312.82	299.53	299.56	313.06	313.23	299.57
1/12/97	313.00	312.96	299.54	299.55	313.05	313.33	299.56
1/1/98	313.09	313.07	299.51	299.52	313.04	313.42	299.52
1/2/98	313.19	313.21	299.57	299.52	313.35	313.43	299.50
1/3/98	313.25	313.26	299.56	299.52	313.35	313.44	299.50
1/4/98	313.25	313.23	299.55	299.47	313.44	313.36	299.47
1/5/98	313.22	313.18	299.63	299.54	313.56	313.29	299.51
1/6/98	313.23	313.17	299.68	299.54	313.56	313.28	299.54
1/7/98	313.12	313.07	299.67	299.52	313.54	313.20	299.55
1/8/98			299.71	299.61			299.60
1/9/98	313.17	313.18	299.68	299.50	313.33	313.30	299.55
1/10/98	313.16	313.18	299.71	299.49	313.30	313.32	299.55
1/11/98	313.22	313.23	299.63	299.48	313.38	313.35	299.56
1/12/98	313.29	313.34	299.63	299.47	313.46	313.40	299.54
1/1/99	313.25	313.43	299.62	299.47	313.39	313.41	299.55
1/2/99	313.35	313.52	299.68	299.39	313.44	313.41	299.64
1/3/99	313.29	313.51	299.64	299.32	313.34	313.39	299.56
1/4/99	313.15	313.34	299.59	299.30	313.20	313.28	299.53
1/5/99	313.26	313.42	299.65	299.35	313.23	313.27	299.60
1/6/99	313.22	313.30	299.72	299.37	313.16	313.19	299.61
1/7/99	313.03	313.09	299.70	299.35	313.02	313.13	299.59
1/8/99	313.01	313.09	299.72	299.41	312.99	313.12	299.64
1/9/99	313.00	313.12	299.73	299.44	312.98	313.12	299.67
1/10/99	312.99	313.17	299.73	299.43	312.95	313.15	299.65
1/11/99	312.97	313.18	299.70	299.37	312.96	313.18	299.62
1/12/99		313.40	299.74	299.46	313.12	313.25	299.69
1/1/00		313.44	299.73	299.41	313.13	313.28	299.66
1/2/00		313.71	299.83	299.61	313.36	313.32	299.75

Appendix B - Field Investigation Data - Permeability Testing

Appendix C - Field Investigation Data – Water Chemistry

Figure C.1: Location of sampling points - Bores

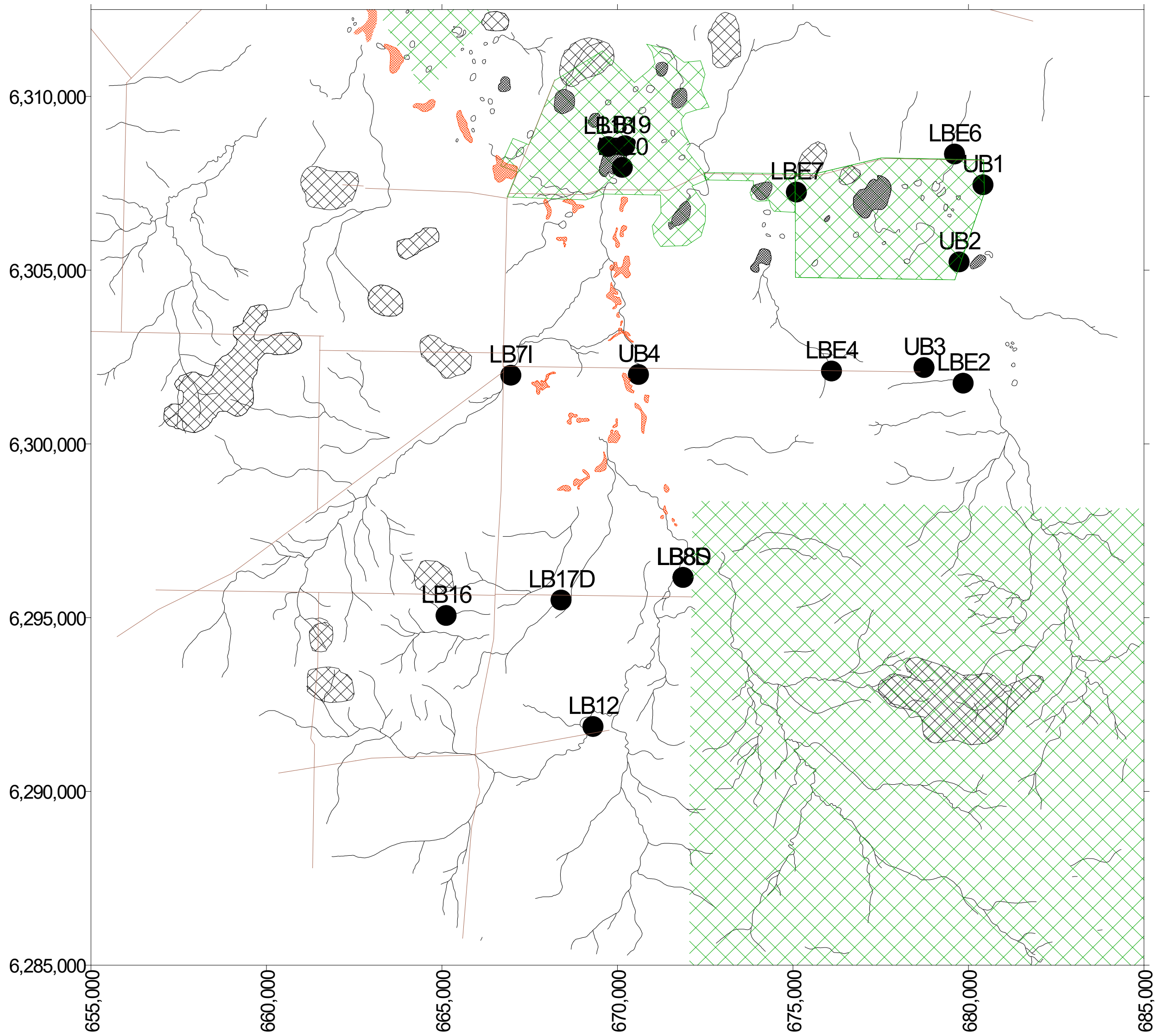


Figure C.2: Location of sampling points - Lakes

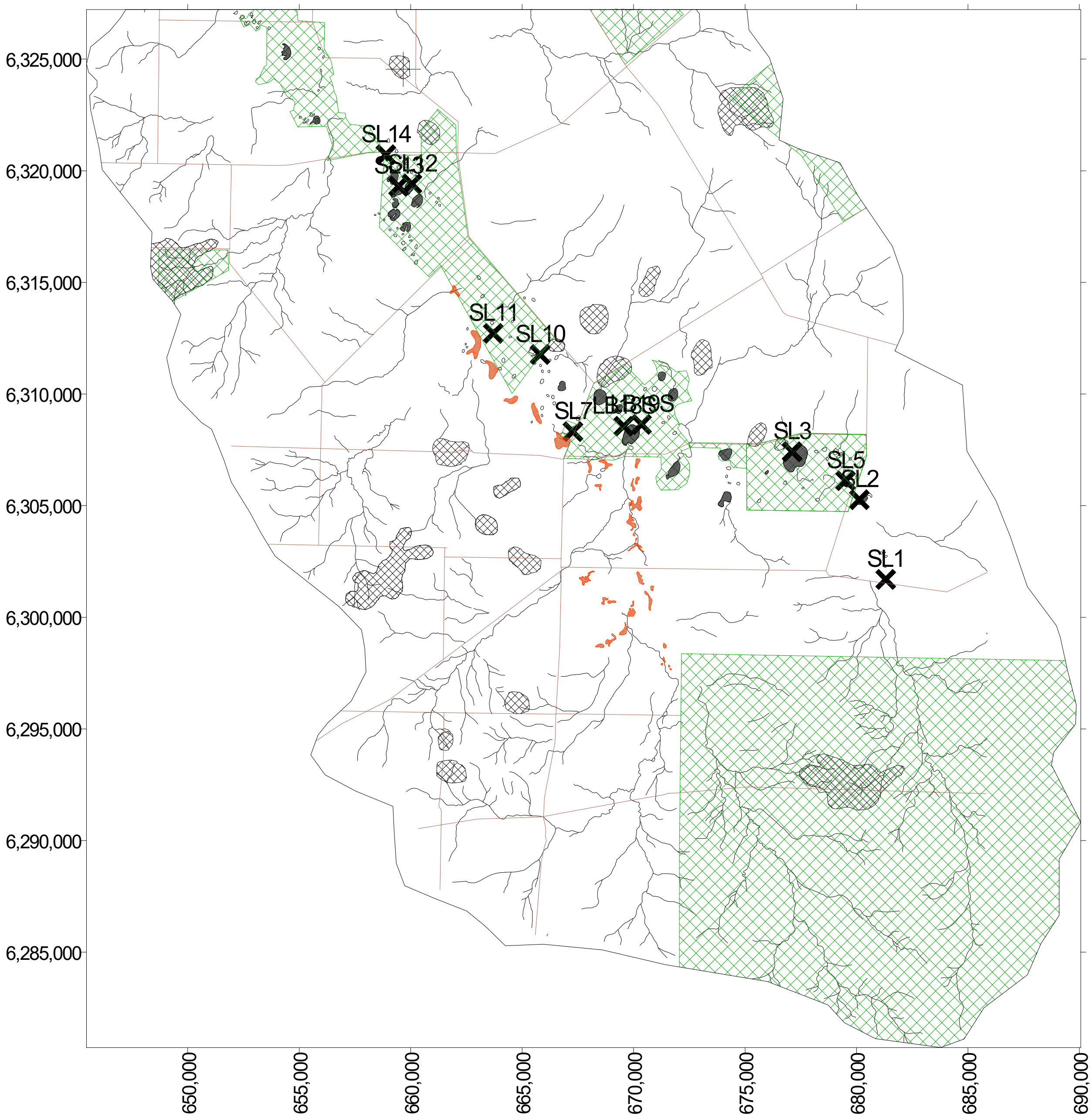


Table C.3: Location and description of sampling points

ID	Description	Date Sampled	Easting	Northing
10A	Bore	26/05/00	661450	6315700
LB12	Bore	24/05/00	669307	6291872
LB16	Bore	25/05/00	665118	6295067
LB17D	Bore	25/05/00	668397	6295511
LB18	Bore	25/05/00	669732	6308561
LB19	Bore	25/05/00	670212	6308585
LB20	Bore	25/05/00	670139	6307958
LB7I	Bore	25/05/00	666967	6301981
LB8D	Bore	25/05/00	671869	6296158
LB8S	Bore	25/05/00	671869	6296158
LBE2	Bore	26/05/00	679850	6301750
LBE4	Bore	26/05/00	676100	6302100
LBE6	Bore	24/05/00	679604	6308344
LBE7	Bore	26/05/00	675100	6307250
UB1	Bore	24/05/00	680416	6307460
UB2	Bore	24/05/00	679733	6305240
UB3	Bore	24/05/00	678736	6302200
UB4	Bore	26/05/00	670600	6302000
Site 1	Lake Bryde	24/05/00	670049	6308804
Site 7	Groundwater discharge zone	26/05/00	663850	6311150
SL1	Lake	25/05/00	681300	6301680
SL10	Lake	26/05/00	665800	6311750
SL11	Lake	26/05/00	663700	6312700
SL12	Lake	26/05/00	660050	6319390
SL13	Lake	26/05/00	659450	6319290
SL14	Lake	26/05/00	658880	6320700
SL2	Lake	25/05/00	680120	6305250
SL3	Lake	25/05/00	677100	6307400
SL5	Lake	25/05/00	679500	6306100
SL7	Lake	25/05/00	667270	6308300
LB18S	Lake Bryde @ LB18	25/05/00	669552	6308541
LB19S	Lake Bryde @ LB19	25/05/00	670350	6308623

Table C.4: Results of testing

ID	EC (mS/cm)	Temp (°C)	Turb (ntu)	DO (mg/L)	DO (% sat)	ORP (mV)	pH	Sal (ppt)
10A	76.4	9.41	351.50	20	300	-95	7.04	52.87
LB12	51.7	13.30	13.4	3.2	37.0	182	5.19	33.97
LB16	46.7	12.95	21.3	6.1	71.6	197	6.85	30.28
LB17D	57.4	13.41	18.2	5.6	66.0	184	5.47	38.20
LB18	68.9	13.31	600	20	300	340	3.81	47
LB19	72.6	13.44	189.2	20.0	300.0	142	7.30	50.04
LB20	80.0	13.64	263.0	20.0	300.0	190	7.18	59.64
LB7I	64.4	13.71	74.9	20	300	421	3.91	42.99
LB8D	1.7	13.88	113.6	1.2	11.6	-136	6.53	0.89
LB8S	58.3	11.20	80.2	0.7	80.0	242	4.58	38.90
LBE2	56.8	13.61	68.4	6.9	81.3	607	3.66	37.74
LBE4	49.0	13.15	600	20	300	125	6.26	32.07
LBE6	65.7	13.11	0.0	0.8	4.6	354	5.17	44.58
LBE7	61.4	12.30	92.2	20	300	189	6.52	41.23
UB1	19.4	13.74	10.9	1.0	10.9	142	6.65	11.50
UB2	77.0	13.90	1.3	0.9	10.0	74	6.74	53.40
UB3	49.8	13.51	572.2	0.9	10.0	-10	6.36	32.32
UB4	23.6	9.95	600	13.3	125.2	200	7.87	14.3
Site 1	2.4	7.89	64.3	17.4	145.4	57	8.40	1.23
Site 7	> 80	11.60	600	20	300	74	8.28	>60
SL1	1.6	4.70	0	20	300	205	7.18	0.5
SL10	13.1	6.46	0	20	300	13	10.32	7.64
SL11	6.9	6.60	12.5	20	300	47	9.18	3.85
SL12	2.4	4.00	600	20	190	5	8.8	1.26
SL13	8.2	5.77	1.9	20	300	29	9.07	4.47
SL14	15.0	4.40	0	20	300	34	9.58	8.76
SL2	8.0	10.15	31.2	20	300	80	9.77	4.47
SL3	0.8	4.17	600	19	153.5	64	9.11	0.38
SL5	0.5	6.06	109	7.7	59.2	102	8.02	0.26
SL7	11.2	6.92	0	19.8	172	36	10.31	6.35
LB18S	3.8	6.51	76.30	20	300	127	8.94	1.46
LB19S	3.4	6.37	98.0	20.0	300.0	-104	8.53	1.75

Notes:

1. Electrical conductivity – upper limit of instrument is 80 mS/cm.
2. Dissolved oxygen – upper limit of instrument is 20 mg/L and 300% saturation.
3. Salinity – upper limit of instrument is 60 ppt.

Table C.5: Water Quality Results - Cations

ID	Na	K	Ca	Mg	Fe
LB 12	11000	95	170	1600	7.5
LB 16	9800	85	270	940	<0.50
LB 17D	15000	130	200	1800	19
LB 18	16000	140	220	2000	9.4
LB 19	18000	110	130	1700	<0.50
LB 20	19000	140	690	2800	<0.50
LB 7I	14000	120	200	2000	1.3
LB 8D	240	9.5	12	30	3.7
LB 8S	14000	190	510	1800	29
LBE 2	12000	110	33	1600	5.1
LBE 4	11000	200	94	1100	3.2
LBE 6	16000	220	82	1500	<0.50
LBE 7	14000	180	220	1700	<0.50
UB 1	4200	59	42	420	<0.05
UB 2	18000	170	190	2100	3.5
UB 3	10000	200	250	1100	<0.50
SL 1	30	11	22	8.1	1.5
SL 2	1400	50	58	120	<0.05
SL 3	130	17	12	13	1.3
SL 4	2100	48	260	220	<0.05
SL 7	1800	44	140	200	<0.05
LB 18S	330	20	58	37	0.25

Notes:
1. All concentrations in mg/L

Table C.6: Water quality results - Anions

ID	CO_3	HCO_3	SO_4	Cl
LB 12	<1	<5	2600	18000
LB 16	<1	190	2100	15000
LB 17D	<1	<5	3300	24000
LB 18	<1	<5	3500	26000
LB 19	<1	420	3800	27000
LB 20	<1	300	6900	32000
LB 7I	<1	<5	3300	24000
LB 8D	<1	75	36	390
LB 8S	<1	<5	3400	23000
LBE 2	<1	<5	2800	20000
LBE 4	<1	65	2100	17000
LBE 6	<1	30	3300	25000
LBE 7	<1	100	3300	23000
UB 1	<1	85	820	6500
UB 2	<1	140	4100	28000
UB 3	<1	280	2600	17000
SL 1	<1	80	30	42
SL 2	<1	360	180	2100
SL 3	<1	150	57	120
SL 4	<1	220	690	3600
SL 7	<1	170	470	3100
LB 18S	<1	170	120	520

Appendix D - Parameter Spatial Distribution

Figure D.1: Hydraulic conductivity spatial distribution

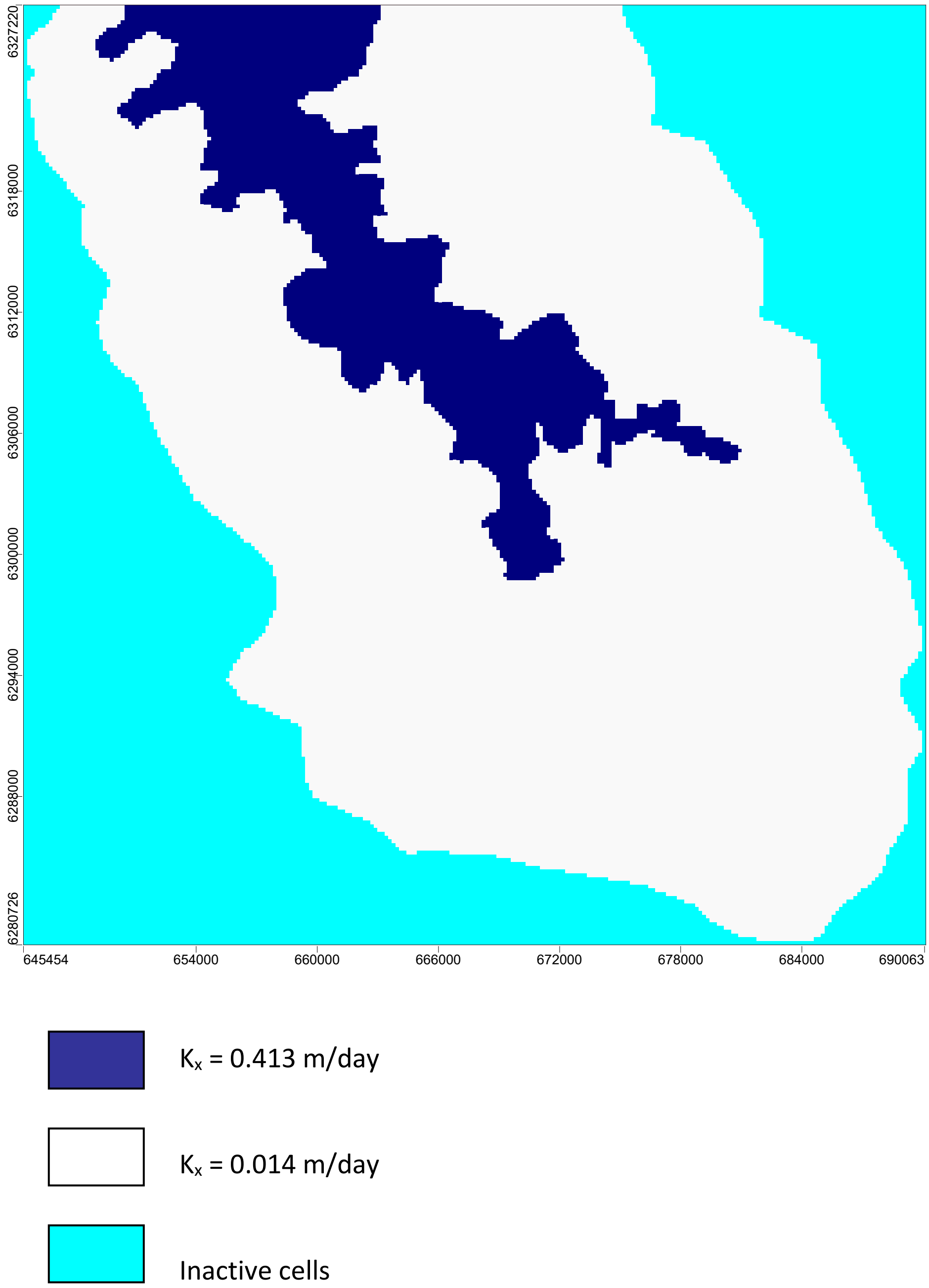


Figure D.2: Recharge spatial distribution

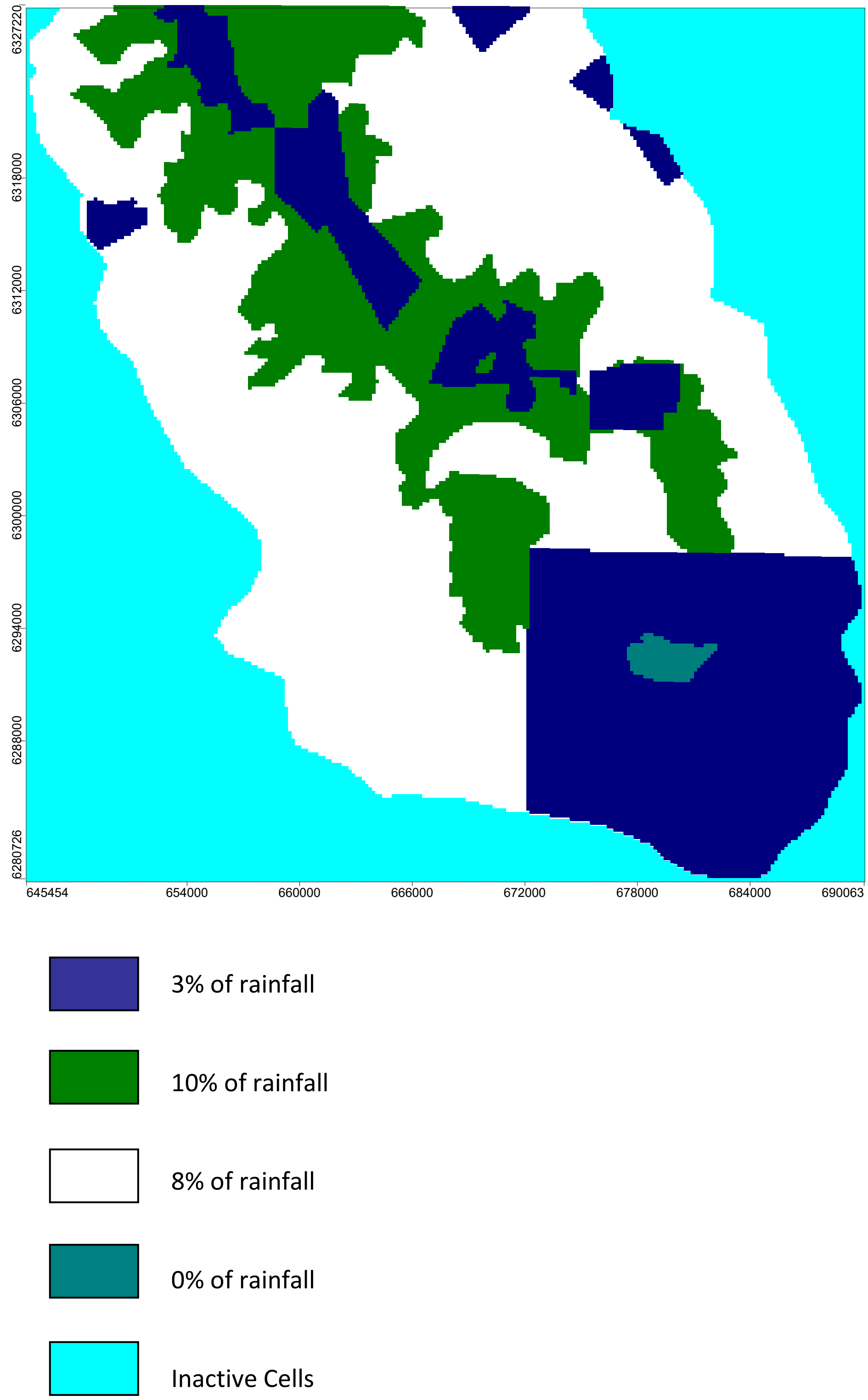
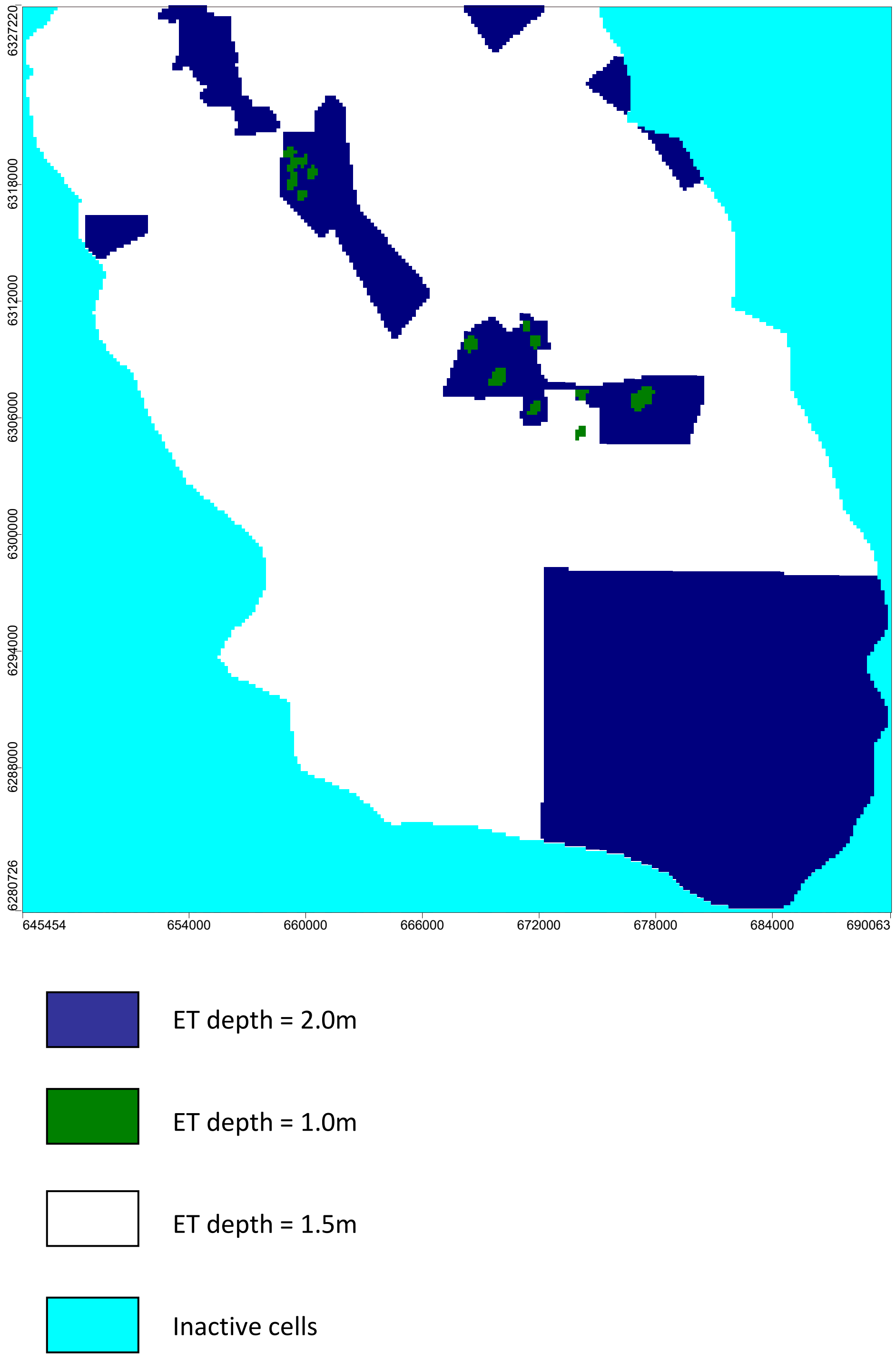


Figure D.3: Evapotranspiration spatial distribution



Appendix E - Modelled and Observed Heads

Appendix F - Photographs From Field Investigation

Appendix G - Geophysical Applications

The use of multiple airborne geophysical techniques for Landcare was initiated by Aerodata and the Western Australian Department of Agriculture (now Agriculture Western Australia) in the mid 1980s (Street et al, 1992; Street, 1992) at East Yornaning. It brought technology and knowledge from mineral exploration to land management. This initiative was concomitant with the development of improved digital recording, computer imaging, better navigation and high-resolution surveys. It is the combination of electromagnetic, magnetic, geological and geographical data that make geophysics a tool in land management.

The National Airborne Geophysics Project (George et al, 1999) showed that airborne geophysics could add significantly to the understanding of catchment processes in areas prone to dryland salinity. In that project five areas were surveyed and interpreted using airborne geophysics. Toolibin Lake another endangered wetland in the southwest of WA was one trial site (Pracilio et al, 1998). Results from that survey were used in a study of salt harvesting potential from the palaeochannel (Actis et al, 1999) and further interpreted (Street and Pracilio, 2000) for CALM using additional ground based data.

Geophysical applications at Lake Bryde will help in defining geological structures, dykes, recharge potential of soils, palaeochannel deposits and shallow bedrock.

G.1.1 Magnetics

The magnetic characteristics of rocks are usually due to the presence of minor amounts of magnetic minerals contained in them (Strangway, 1967). Although all minerals are magnetic to some extent, those of significance are the oxides of iron in the solid solution series magnetite-ulvospinel, heamatite-ilmenite; and magnetite-maghemite plus the iron sulphide, pyrrhotite.

Rocks with a more basic chemistry such as are found in dykes of dolerite and/or gabbroic composition usually contain a higher content of minerals that have significant magnetic susceptibilities. Thus dolerites are easy to map using magnetic surveys and generally appear as linear magnetic highs on maps of magnetic intensity.

In the aeromagnetic method a magnetometer sensor mounted in a stinger at the rear of the aircraft measures the total magnetic field of the earth as the aircraft flies at 60 metres above the ground. Short wavelength variations in the magnetic field are due to variations in the magnetic mineral content of the rocks near to the surface of the ground. Longer wavelength variations are usually due to deeper sources.

Elsewhere in the wheatbelt of Western Australia ground and airborne magnetic surveys have been used for salinity by mapping position of dolerite dykes and other geological units which cause localised salinity (Engel et al, 1987; Townrow, 1989; Anderson and Street, 1994). At Toolibin Lake, George et al (1996) used magnetic surveys to position the pumping bore sites.

At Lake Bryde magnetic surveys will map the position of dolerite dykes which appear to be associated with salinity in the areas of lateritic weathering over most of the upper parts of the catchment. Knowledge of the accurate position of dykes allows better positioning or remedial measures designed to overcome the changes in regolith permeability.

G.1.2 Radiometrics

Gamma-ray spectrometry (radiometrics) measures the natural gamma radiation emitted by radioactive daughter decay of three elements - potassium (K), thorium (Th) and uranium (U) - from within approximately the top 30cm of the earth's surface. The maps prepared from radiometric surveys provide information about the soil parent materials and other properties such as surface texture, weathering, leaching, soil depth and clay types (Bierwirth et al, 1996a).

Cook et al. (1996) used gamma radiometric surveys as a guide to soil mapping in the West Australian wheat belt and found that the variation in radiation corresponded to the distribution of soil-forming materials over the landscape. Radiometrics were used to distinguish between highly weathered residuum and fresh granitic material. Radiometric data also distinguished between doleritic, lateritic and granitic soils (Cook et al, 1996).

The radiometric elements measured are derived from a number of sources in rocks and regolith. Where shallow bedrock is present radiometric responses tend to be higher (except in sandstone areas) and relate to the properties of the bedrock (Bierwirth et al, 1996b). In areas where soils have formed, the signature is related to physical and weathering processes (Bierwirth et al, 1996b). In areas of transported material radiometrics can reflect the transport and depositional history. The following is a summary of radiometric data and its relationship to soil properties.

At Toolibin Lake, Street and Pracilio used radiometric in conjunction with soil pit data to produce a detailed soil map usable to 1:10,000 scale for catchment and farm management. Radiometrics is perhaps the only presently available method that can cost effectively measure variability in the top 1 metre of the soil. By using the resolution of a close spaced radiometric survey it is possible to extend soil characteristics derived from ground investigations over large areas. Present work by Cook and Pracilio utilises radiometrics to produce maps of the 'leakiness' of soils or the amount of recharge that occurs in different soil types.

At Lake Bryde radiometric surveys will map soil variability within paddocks to produce soil maps usable down to 1:10,000 scale or better. Specifically radiometrics will map in detail the sandier soils where recharge is greatest along the edge of the valley sediments. These areas will need to be targeted for remedial action to reduce recharge. Conversely radiometrics will map the areas where recharge is likely to be least and where minimal remedial actions are necessary.

G.1.3 Electromagnetics

Except for the metallic sulphides, graphite and native metals most rock forming minerals are very resistive. In contrast electricity in weathered or highly permeable rocks and soils, which have inter-granular pore fluids, the electrical conductivity is principally electrolytic through the movement of ions in the pore fluid and the soil. The rock matrix can be assumed an insulator. The electrical conductivity of soils and porous rocks is influenced by:

- Soil structure - or porosity and shape of pore spaces;
- Moisture content or degree of saturation;
- Salt content of the soil moisture;
- Clay mineralogy or the presence of clays with cation exchange capacity; and
- Temperature.

In the southwest of WA the primary cause of variation in electromagnetic response is the distribution of salt, most of which is stored in the sub-surface clays in the regolith. The origin of the salt is considered to be primarily from rainfall (Hingston, 1958; Hingston and Gallitis, 1976).

The permeability which is controlled by the amount of clay in the regolith is a major control on salt concentration in the regolith. Water moving through clay dominated regolith, is more likely to be intercepted by vegetation leaving the salts behind. A sandy regolith allows water to pass through at relatively rapid rates due to its high permeability. Another major control is topography and in most cases in the southwest of Australia topographic control appears to dominate over permeability. Therefore electromagnetic data can be used to interpret areas of higher permeability in the landscape.

Typically palaeochannel sediments such as are indicated at Lake Bryde are lower in conductivity than surrounding granitic saprolite regolith. Despite the sands in the palaeochannels having high yields of groundwater extraction they have a lower porosity than surrounding granite-saprolite regolith and therefore contain less water and less salt.

G.2 Products from Geophysical Surveys

In the past, only data that reflects surface conditions have been available in salinity studies. These include airphotos, satellite imagery and topography. Limited understanding of subsurface conditions has been achieved by drilling. Much more can be gained from the use of airborne geophysics.

At Lake Bryde the collection of detailed airborne geophysical survey data will improve the understanding of both local and regional processes that are controlling salinity.

Typical interpretation products that can be produced using airborne geophysical (and other) data are in **Table G.1**.

Table G.1: Interpretation maps and data used to derive interpretation

Interpretation Product	Interpretation Type	Airborne Data	External Data
Solid Geology Showing dykes, faults and granite boundaries	Qualitative	- Magnetic Intensity	- 1:250,000 Geology Map
Regolith Maps Soils Maps Leakiness Maps	Qualitative	- Radiometric Ternary - Potassium - Thorium - Uranium - Total Count - DTM	- 1:250,000 Geology Map - Drainage
Electromagnetic (Computer Modelling and Analysis products)	Quantitative Computer Models 1) Three layer inversion model 2) Look up table	**1). Inversion of EM data** Thickness of regolith Bedrock topography Conductivity of regolith in 3D Sections Depth slices at 4 metre intervals	- EM-39 - $EC_{1:5}$ - Groundwater salinity The above three data sets can be used in the qualitative interpretation of computer modelled and analysed products.
Hydrogeology (Water Resource Target Map)	Qualitative	All of above interpretation and image products.	As above plus - Rainfall - Groundwater level - Mapped soaks - Reports supplied - DOLA DEM
Salt Hazards	Qualitative	All of above interpretation and image products.	As above plus - air photo mosaic

G.3 Recommended Minimum Survey Parameters

G.3.1 General

Flight line spacing-	150m or less
Flight line direction-	~045° – 225°
Tie line spacing-	1,500m (10x line spacing)
Tie line direction-	135° – 315° (orthogonal to lines)
Radar altimeter cycle rate-	10Hz (0.1s), ~7m
Barometric altimeter cycle rate	10Hz (0.1s), ~ 7m
Humidity sensor cycle rate	10Hz (0.1s), ~ 7m
Temperature sensor cycle rate	10Hz (0.1s), ~ 7m
GPS cycle rate	1Hz (1s), ~ 70m
Datum	AGD84 (or new MGA)
Zone	50
Central Meridian	117 degrees East

NOTE: Final specifications should be decided based on the aim of the survey and to lesser extent the budget available. Type of systems employed will also need to be considered.

G.3.2 Magnetics and Radiometrics

Magnetics/spectrometer sensor height 60m max (lower if safety permits)
Magnetometer cycle rate 10Hz (0.1s), ~ 7m
Magnetometer resolution 0.001 nT
3 Axes Fluxgate Magnetometer 10Hz (0.1s), ~ 7m
Spectrometer cycle rate 1Hz (1s), ~ 70m
Base station magnetometer cycle rate 1 second
Spectrometer crystal volume 32 litres (48 if possible)

NOTE: Radiometric data quality is much improved at lower altitude and by increasing crystal volume. A 32 litre crystal volume should be a minimum at 60 to 80m altitude. Radiometric data is best collected in dry periods because water on the surface can adsorb gamma radiation.

Experience has shown that the above magnetic specifications will detect almost all dykes of significance. However, lower and faster sampling would make interpretation easier.

AEM

System	Time Domain
Frequency Range	500 Hz to 50 KHz
AEM Transmitter cycle rate	5Hz average, 12.5m
AEM flying height	120m
AEM receiver height	45 to 50m
Receiver orientation	x and z components
Receiver sampling rate	10 microsecond intervals

NOTE: Recent developments in AEM systems have resulted in the new TEMPEST AEM system (Lane et al, 1998) which was derived from SALTMAP. This system has the best resolution of vertical changes in regolith conductivity. Other cheaper helicopter and fixed wing systems are improving and new systems are appearing on the market. All frequency domain systems have calibration problems although newer systems appear more stable. The older GEOTEM and QUESTEM systems should not be considered over TEMPEST.

Appendix H - Details of Observation Bores and Piezometers

Table H.1: Details of Observation Bores and Piezometers

Bore ID	Easting	Northing	NSL (mAHD)	Date Drilled	Depth Drilled	Slotted Interval	Stick Up
LB1D	667700	6302900	304.3	20-Feb-95	38.0	13.23 - 15.23	0.69
LB1I	667700	6302900	304.3	20-Feb-95	-	0.0 - 2.0	0.65
LB1S	667700	6302900	304.3	20-Feb-95	0.4	0.0 - 0.4	0.64
LB2D	667662	6303074	304.5	21-Feb-95	14.0	12.0 - 14.0	0.72
LB2ID	667662	6303074	304.5	21-Feb-95	6.0	4.0 - 6.0	1.30
LB2IS	667662	6303074	304.5	21-Feb-95	-	1.5 - 3.5	1.21
LB2S	667662	6303074	304.5	21-Feb-95	1.0	0.0 - 1.0	1.16
LB3D	667486	6303093	304.4	21-Feb-95	14.0	12.0 - 14.0	1.36
LB3I	667486	6303093	304.4	21-Feb-95	-	2.0 - 4.0	1.40
LB3S	667486	6303093	304.4	24-Apr-97	-	0.0 - 0.5	0.82
LB5D	664655	6299399	315.4	22-Feb-95	14.0	12.0 - 14.0	1.25
LB5S	664655	6299399	315.4	22-Feb-95	-	0.5 - 2.5	1.38
LB6D	664678	6299387	315.4	22-Feb-95	14.0	12.0 - 14.0	1.35
LB6I	664678	6299387	315.4	23-Feb-95	5.0	3.0 - 5.0	1.35
LB6S	664678	6299387	315.4	23-Feb-95	-	0.0 - 1.0	1.18
LB07s	666967	6301981	306.3	05-Mar-96	3.3	2.95 - 3.95	0.60
LB07d	666967	6301981	306.3	05-Mar-96	18.0	12.01 - 14.01	0.63
LB08d	671869	6296158	303.0	07-Mar-96	27.0	25.0 - 27.0	0.81
LB08s	671869	6296158	303.0	07-Mar-96	9.0	7.74 - 9.74	0.71
LB09d	670657	6298615	300.0	07-Mar-96	24.0	22.19 - 24.19	0.72
LB09s	670657	6298615	300.0	07-Mar-96	9.0	7.56 - 9.56	0.67
LB10s	674863	6292206	309.7	08-Mar-96	20.0	10.2 - 12.2	0.82
LB10i	674863	6292206	309.7	08-Mar-96	15.8	14.51 - 16.51	0.68
LB11	678010	6292180	328.1	08-Mar-96	31.0	29.95 - 31.95	0.50
LB12	669307	6291872	312.7	09-Mar-96	27.0	24.87 - 26.87	0.69
LB13	669342	6288237	328.4	08-Mar-96	41.2	39.95 - 41.95	0.53
LB14	661622	6290771	343.0	11-Mar-96	29.0	27.43 - 29.43	0.39
LB15	659125	6295649	337.6	11-Mar-96	19.0	17.6 - 19.6	0.68
LB16	665118	6295067	329.1	11-Mar-96	33.0	30.75 - 32.75	0.49
LB17d	668397	6295511	309.7	11-Mar-96	32.0	30.9 - 32.9	0.38
LB17s	668397	6295511	309.7	11-Mar-96	6.0	4.32 - 6.32	0.40
LB18	669732	6308561	294.9	12-Mar-96	9.0	7.85 - 9.85	0.92
LB19	670212	6308585	294.4	12-Mar-96	6.0	4.55 - 6.55	0.73
LB20	670139	6307958	294.6	12-Mar-96	9.0	7.3 - 9.3	0.37
LBE2	679850	6301750	307.3	03-Apr-00	12.0	10.0 - 12.0	0.43
LBE4	676100	6302100	322.6	03-Apr-00	30.0	28.0 - 30.0	0.41
LBE6	679604	6308344	307.2	03-Apr-00	24.0	21.2 - 23.2	0.40
LBE7	675100	6307250	298.6	03-Apr-00	15.0	13.0 - 15.0	0.50
10A	661450	6315700	287.8	-	-	-	-
12A	661300	6316000	287.7	-	-	-	-
UB1	680416	6307460	309.4	-	-	-	-
UB2	679733	6305240	299.8	-	-	-	-
UB3	678736	6302200	326.2	-	-	-	-
UB4	670600	6302000	297.3	-	-	-	-