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# Lake George Basin

# Groundwater Sustainability Investigation

# Bungendore

# for

# Palerang Council

# Final Report

**Distribution:**
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# 1.0 EXECUTIVE SUMMARY

Palerang Council engaged *Hydroilex Pty Ltd* to undertake a regional evaluation of the Lake George catchment and associated groundwater system, to determine the hydrogeological controls, and likely sustainable levels of abstraction to service the village of Bungendore, and various plans for its growth. A programme and budget was presented to Council, and approved in December 2004.

The principal ***objectives*** of the investigation were focussed on the following:

- To determine the distribution and regional geological controls of recognised groundwater resources in the area, particularly associated with the Turallo Creek catchment.
- Source comprehensive datasets to calibrate a 'groundwater model', incorporating knowledge of recharge potential, recorded abstraction rates, pumping history, groundwater monitoring data, climatic data, and aquifer hydraulic characteristics.
- Incorporate the hydrogeological controls, regional geological understanding, and defined boundaries of the aquifer system into a realistic calibrated 'groundwater model' from which sustainable levels of groundwater abstraction could be determined.
- Provide and specify an improved level of groundwater monitoring and management of the resource.
- Define additional sources of groundwater abstraction in satisfaction of the results of the investigation.
- Provide recommendations to Council for submission to *DIPNR*, from which a groundwater policy could be determined, for both the protection and continued exploitation of a sustainable groundwater resource.

The ***methodology*** employed to reach the above objectives were:

- Acquisition of airborne geophysical data over a selective area of the 'blind' alluvial systems from which the village currently abstracts its town water supplies.
- Mapping of the fractured-rock terrains using conventional geological techniques, and existing geophysical data.
- Collation of all available geological and hydrogeological data in the area, including monitoring bore data, recorded abstraction data, discharge data and published geoscientific data.
- Interpretation of unpublished 'recent' airborne magnetic and radiometric data acquired by the Department of Mineral Resources, and integration of this interpretation into the regional understanding.
- Collection of historic climatic data from a number of weather stations in the area. A review of various aspects of global warming and the likely effects on rainfall patterns has been conducted in an effort to assess trends in aquifer recharge risk, related to sustainability in the medium term.
- Acquisition of borehole geophysical data and installation of a water level recording device on Lake George.

The investigation has been conducted by *Hydroilex Pty Ltd*, utilising specialist services provided by:

| | |
|---|---|
| *Geotech Limited* (Canadian-based) | Contractor, providing the airborne VTEM survey and data analysis |
| *Steve Webster Pty Ltd* | Consultant, providing geophysical interpretation and associated data processing |
| *University of NSW Water Research Laboratory* | Consultants, providing an analysis of the hydrologic and hydrogeological data, and generation of a complex groundwater model. |

The investigation has ***concluded*** with a number of findings, which are detailed in the report, accompanied by comprehensive databases. The following are the main results:

- The methodology, as applied to the project area, has been successful in its objectives.
- The airborne geophysical (VTEM) survey has successfully defined the distribution of the 'buried' alluvial channels.
- Data derived from the geological, geophysical, hydraulic, climatic, abstraction, and monitoring bore data has been successfully used to calibrate and develop a groundwater model.
- A relatively complex groundwater model has been developed as a 3/4-layer (3D) model over the Turallo Creek catchment, within both the alluvial aquifer system and the fractured bedrock. The model, over an area of ~200km$^2$ has been developed with the creation of ~10,000 cells having an area of 1-10 hectares.
- The groundwater model has been calibrated over a limited period of time (4 years of monitoring bore data, and 2 yrs of accurate pumping data). The modelling demonstrates that there is a high level of sensitivity to rainfall, and that recharge of rainfall is lower than expected. The model predicts that recharge represents 1% of rainfall, compared to prior studies (Jacobson et al, 1991), where ~8% of average rainfall was contributed as runoff into the catchment. It is believed that the majority of runoff contributes to the groundwater system.
- The groundwater model has determined that the current usage (~700 ML/yr) is at or near the sustainable yield, at the 2002-2004 level of rainfall, which is below the long term average rainfall of 650mm/year. That is, the current usage is a large proportion of present recharge.
- Pumped groundwater is sourced by the interception of outflow water into Lake George, without any evidence that pumping is removing significant groundwater from aquifer storage.
- There is an insufficient period of groundwater monitoring to determine any long term groundwater level trends, and the conclusions reached are based on limited datasets and uncertainties of the spatial and temporal usage of groundwater (particularly irrigation water).
- Both groundwater modelling, and water balance calculations conclude that the groundwater system is not under stress, but at a level that is close to the 'sustainable yield', based on *DIPNR* definitions, where management requires "*additional work to*

*refine the sustainable yield value, with close scrutiny of new entitlements necessary to manage within the adopted limit".*

- The groundwater model has determined that the least impacts of groundwater pumping on the existing system will be afforded by:
    - Locating any new bores within the fractured rocks, >1km from the alluvium, where there will be no impacts on alluvial aquifers.
    - Minor impacts on groundwater levels within alluvial aquifers if new bores are located near existing bores.
    - Locating new bores within the alluvial channel close to the discharge into Lake George will have no impacts.
- The status level of increased groundwater abstraction at Bungendore relies on determinations by *DIPNR* as to the allowable levels of pumping from aquifer storage without inducing environmental stress.
- Outside of the Turallo Creek catchment there is significant groundwater potential within the Butmaroo Creek catchment, 5-8 km to the east and northeast of Bungendore. This region may represent an alternative groundwater source in the future.

# 2.0 INTRODUCTION

This report provides the results of an aquifer sustainability investigation conducted in the region of Bungendore, designed to determine the likely levels of groundwater abstraction which will sustain the level of urban growth in the region.

The study has been commissioned by Palerang Council, and following its endorsement by *DIPNR*, will serve to provide the necessary scientific and technical data to assist in the determination of a groundwater policy for the region.

The key elements of the investigation were set out in a programme and budget presented to Council in December 2004, comprising:

- Regional data collation and compilation in digital format.
- Geophysical interpretation of Department of Mineral Resources (Braidwood Survey).
- Geological structural analysis of the Lake George catchment.
- Acquisition of airborne electromagnetic data over the alluvial part of the Turallo Creek catchment (VTEM).
- Preparation of a groundwater computer model.
- Installation of piezometers.
- Ground geophysics and borehole geophysics in AGSO bores on Lake George.
- Installation of water level data loggers.
- Delineation of groundwater targets for additional groundwater supplies.
- Review of climatic variations and impacts of global warming.

The study has been documented in three main components, comprising the following content and authorships:

- Overview and geological analysis *(Hydroilex Pty Ltd)*
- Regional Geological and Geophysical Interpretation *(Steve Webster Pty Ltd)*
- Helicopter-borne Electromagnetic (VTEM) survey report *(Geotech Limited)*
- Interpretation of VTEM survey *(Steve Webster Pty Ltd)*
- Groundwater Flow Model *(UNSW Water Research Laboratory)*

The investigation has been conducted consistent with the defined programme and budget, as designed using a significant database of in-house studies, conducted both on behalf of Council and developers. An inventory of selected references is provided in this report. The database has been preserved in both Mapinfo and ArcGIS formats.

## 3.0 CATCHMENT DRAINAGE DISTRIBUTION

The investigation has been focussed principally on the Turallo, Halfway and Millpost Creek drainage systems which have an aggregate area of approximately 200 $km^2$. This catchment has been the focus of groundwater modelling within alluvial and fractured rock aquifer systems. The catchment drainage of the southern part of the Lake George Basin is shown in Figure 1 and Plate 1.

The geological analysis of the region has been extended to include the Butmaroo Creek catchment located in the eastern sector of the basin. This region has a significant groundwater potential from fractured-rock aquifers.

Lake George is a structural basin, having its landform development dominated by 'sagging' along a half-graben, associated with the Lake George Fault. The drainage style of the basin is characterised by a medium density of ephemeral streams located in the more elevated parts of the catchment. In the lower parts of the catchment, the more 'mature' drainage is captured by fracture systems in the bedrock, which in turn, are considered to be in direct communication with medium to coarse alluvial aquifers known to exist in the sub-surface.

# 4.0 AQUIFER CHARACTERISTICS AND RECHARGE

Figure 2 is a synthetic diagram which links the hydrological and hydrogeological components of the Lake George aquifer system. Aquifers are associated with:

- Alluvial channels – comprised of Quaternary-aged unconsolidated gravel and sand deposits are dominantly confined to two palaeo-valley systems separated by a central zone of elevated basement relief. The eastern margin of the western channel is fault-controlled, as defined by airborne magnetic data (VTEM survey). The channels capture groundwater from springs, surface water, and deeper fracture zones, from where it discharges into Lake George. The western channel is deeper, and the eastern channel is possibly younger. The distribution and characteristics of these channels are shown in Plates 4, 5 & 6. The existing water supplies at Bungendore are sourced from these channels. Town water supply Bore 2 (Gundarro Rd) sources from the western channel, and Bores 1, 3 & 6 from the eastern channel. Hydraulic characteristics of Bores 1, 2 &6 have been used to develop the groundwater model.
- Significant aquifers associated with fracture zones in the basement rocks are recognised mainly to the east of Bungendore within rock sequences of Ordovician age. Hydraulic characteristics of these bores have been used to develop the groundwater model. Plate 3 shows the distribution of fracture trends, as interpreted from aerial photo images. A statistical analysis of these trends was applied to the groundwater model. The dominant fracture orientation is $070^0$ (70%), secondary trend is at $130^0$ (20%), and tertiary trend is at $180^0$ (10%). The latter excludes the very significant N-S trends associated with the basin-controlling structures.

Groundwater recharge is the entry of groundwater into the saturated zone of the soil or bedrock to the water table, with an associated flow away from the entry point within the saturated zone. Recharge is associated with both direct meteoric waters from rainfall and 'perched' groundwaters entering the system.

In the Lake George catchment the main elements of recharge are:

- Rainfall, evaporation and rainfall patterns.
- Distribution and porosity of joints, fractures and faults, which capture surface waters.
- Distribution of porous and permeable sediments, and weathered rocks.
- Land use activities.
- The density of farm dams.
- Porosity and permeability of the principal aquifer systems.
- Elevation of the lake, which is the groundwater base level.
- Elevation of the surrounding topography and hydraulic head.
- Lake George has a total area of approximately $932km^2$ of which the Turallo and Millpost Creek catchments have an area of approximately $200km^2$. The lake itself is only 16% of the total catchment area.
- Under 'normal' climatic conditions, the lake receives approximately 50,000 ML of run-off per year.

The following points summarise additional features of the groundwater system, and impacts of abstraction from it, compared to those in adjacent catchments:

1. Groundwater management needs to recognise the preservation of groundwater dependent ecosystems. Since the streams in the area are dominantly perennial, and largely perched above thick clay sequences in the vicinity of the township, there are not considered to be any recognised impacts on surface water environments in Bungendore region. That is, there are no permanent 'flowing streams' and accordingly there are no 'strict' surface environmental flows, which have associated ecosystems.
2. The majority of the groundwater abstraction is associated with alluvial aquifers having a significant storage. The situation is dissimilar to the Yass, Jerrabomberra Creek and fractured rock sub-catchments in the Canberra region, which are associated exclusively with fractured rock aquifers.
3. The alluvial aquifers which are more directly linked to surface drainage , and fracture rock aquifers extend well beyond the limits of the catchment basins.
4. Lake George is an evaporative lake without a discharge, and the combined effects of groundwater and surface water input contribute to the total water volume, which is lost by evapotranspiration processes.
5. Groundwater discharge waters from higher potentiometric relief in the south towards the north into Lake George.
6. The variable salinity of the water in the lake is not conducive over extended periods to the support of animal and plant life in the lake and bottom sediments. Fish have been reported in historical times.
7. There is very limited use of surface water in the catchment (dams, creeks). This is in strong contrast to the situation in the Yass catchment, where there is a significant over-allocation of surface water resources, and the consequence of a specific-purpose groundwater embargo.

# 5.0 REGIONAL AEROMAGNETIC INTERPRETATION

An interpretation of the *Department of Mineral Resource* (NSW Department of Primary Industries - DPI) regional airborne magnetic, radiometric and elevation data has been completed by *Steve Webster and Associates.* The interpretation is provided in *Appendix 1*.

The report provides an interpretation of the data, which has been subsequently integrated with geological and airborne electromagnetic survey (VTEM). Aeromagnetic data derived from the VTEM survey, being of higher resolution than the DPI survey, has enabled a greater understanding of the basement relief, and structural controls on the distribution of the alluvial channels.

The principal results of the interpretation have been used to assist in the development of the groundwater model. The analysis has provided an improved understanding of:

- Basement magnetic characterisation and geological control.
- Distribution of major faults and structural trends.
- Radiometric signatures of the surficial sediments.

# 6.0 AIRBORNE ELECTROMAGNETIC SURVEY (VTEM)

The helicopter survey was flown in late April 2005 by *Geotech Limited*, over an area covering the alluvial drainage of the catchment, as shown in Figure 1. A total of 175 line km of data was acquired over a 4km x 10km grid, with lines spaced at 250m. Forty one (41) E-W lines and 5 N-S tie lines were recorded. The survey extends from Millpost Lane to the southern margin of the lake. The area of the township could not be surveyed due to safety issues.

The geophysical technique, introduced commercially in late 2002, uses a 26m diameter loop transmitter, receiver and magnetometer suspended approximately 50 metres below the helicopter, and flown at an elevation of 30-35 metres above the ground. The depth of investigation is up to 200 metres below ground level. Profiles of resistivity –depth and various electromagnetic and magnetic data analysis plots generated by *Geotech Limited* are provided in *Appendix 3*. Typical profiles, which depict the responses of the alluvial channels are shown in Figure 3.

An interpretation of the survey was conducted by Steve Webster Pty Ltd, as provided in *Appendix 2*. A deconvolved response image of an 'early' time electromagnetic channel is provided in Plate 4, and depicts the position of the conductive alluvial system.

Plots of VTEM data for 'early' time channels clearly show the two alluvial valleys that we know to exist. The western valley shows higher conductivity (profiles have higher relief) than the eastern valley and tributaries from the west, discharging from the Lake George Range are also shown to merge with the drainage, as noted in the Millpost Creek area.

The excellent survey data quality will obviate the need for ground geophysical follow-up of anomalies (as programmed), and the drilling of groundwater objectives within the airborne-defined alluvial zones is considered to be of relatively low risk.

# 7.0 GROUNDWATER MODELLING

A groundwater model has been prepared by the University of NSW Water Research Laboratory. A comprehensive report is provided as *Appendix 4*.

The model has incorporated all geologic data over the catchment area, of which 172 km2 has been designated as 9,976 active cells, having a size of 1 – 10 hectares. The model was initially structured as a 2 layer model of the alluvium, and subsequently expanded with the addition of two layers in the fractured rock. The groundwater model has concluded:

- The groundwater model has been calibrated over a limited period of time (4 years of monitoring bore data, and 2 yrs of accurate pumping data). The modelling demonstrates that there is a high level of sensitivity to rainfall, and that recharge of rainfall is lower than expected. The model predicts that recharge represents 1% of rainfall, compared to prior studies (Jacobson et al, 1991), where ~8% of average rainfall was contributed as runoff into the catchment. It is believed that the majority of runoff contributes to the groundwater system.

- The groundwater model has determined that the current usage (~700 ML/yr) is at or near the sustainable yield, at the 2002-2004 level of rainfall (416 – 500mm/year), which is below the long term average rainfall of 650mm/year. That is, the current usage is a large proportion of present recharge.
- Pumped groundwater is sourced by the interception of outflow water into Lake George, without any evidence that pumping is removing significant groundwater from aquifer storage.
- There is an insufficient period of groundwater monitoring to determine any long term groundwater level trends, and the conclusions reached are based on limited datasets and uncertainties of the spatial and temporal usage of groundwater (particularly irrigation water).
- Both groundwater modelling, and water balance calculations conclude that the groundwater system is not under stress, but at a level that is close to the 'sustainable yield', based on *DIPNR* definitions, where management requires "*additional work to refine the sustainable yield value, with close scrutiny of new entitlements necessary to manage within the adopted limit"*.
- The groundwater model has determined that the least impacts of groundwater pumping on the existing system will be afforded by:
    - Locating any new bores within the fractured rocks, >1km from the alluvium, where there will be no impacts on alluvial aquifers.
    - Minor impacts on groundwater levels within alluvial aquifers if new bores are located near existing bores.
    - Locating new bores within the alluvial channel close to the discharge into Lake George will have no impacts.

## 8.0 GROUNDWATER ABSTRACTION

*DIPNR* have provided data for all registered bores, and from this data various plots have been compiled. The Licence Administration System (LAS) of *DIPNR* has provided the necessary specific usage and allocation data for all bores in the designated catchment.
Table 1 provides a summary of the available data.

**Table 1. Summary of groundwater abstraction levels and allocations**
* Unconfirmed by DIPNR

| **Licensed Bores** | **Numbers of Licenses** | **Annual Allocation ML** | **Approx. Current Nett Usage** |
|---|---|---|---|
| Stock & domestic | 118 registered many test bores, monitoring bores (assume 70) @ 1ML? | 70* | 70* |
| Town water | 4 | 322 | ~280 |
| Irrigation & farming | ~ 5? | 700* | 500 |
| Return Flow from Bungendore STP | | | *150ML* |
| **Totals** | | **~ 1100*** | ~ 700 |

# 9.0 CLIMATIC VARIABILITY

'Climate change' is an important issue which is likely to have an impact on total rainfall, seasonal changes to rainfall patterns, and rainfall frequency. Variations in rainfall will impact on the rate of aquifer recharge, and affect long-term abstraction planning in the region.

The causes of climate change are both complex and subjective. The acceleration of global warming and correlable increases in $CO_2$ emissions is well-recognised. The cyclic (probably celestial-related) variation in rainfall on 30-50 year cycles is also apparent in rainfall and water level data from Lake George. Much longer climatic cycles of the order of 1-5Ma are recognised in the geological record. The combined effects of these superimposed trends however make it difficult to generate reliable predictions, and it appears that there is considerable debacle over the various predictions by various agencies.

The following summarises some important facts, theories and interpretations published by various experts in climatology, palaeoclimatology and related sciences: (references have not been cited explicably, but mainly sought from CSIRO publications)

- Most of the effects of global warming over the last 50 years are attributable to human activities ($CO_2$ emissions from the burning of fossil fuels and land clearing) which have increased greenhouse gases in the atmosphere. There has been a 31% increase in CO2 concentrations in the atmosphere since 1750.
- In the same 50 years there has been a global increase in sea level (0.12-0.16m since 1900), extreme maximum temperatures, extreme precipitation, and Australian droughts have become hotter for a given rainfall deficiency.
- The earth is now absorbing more energy from the sun than it is emitting to space. The imbalance is absorbed in the increase in ocean temperatures.
- Australia's average temperature has increased by $0.8^0$C since 1910, minimum temperatures rose by $1.0^0$C and maximum temperatures rose by $0.6^0$C, with the largest increases over northern and western Australia. *In the Bungendore region, the maximum temperature has increased by 0.1-0.2$^0$C/ 10 years since 1950. Minimum temperatures have increased by 0.1$^0$C/10 years.*
- Annual average precipitation has decreased in eastern Australia since 1950, with increases in the north-west.
- In Australia since 1957, the number of extremely hot days and warm nights has increased, while the number of extremely cool days and cold nights has decreased, also corresponding to a reduction of the number of frost days.
- In NSW there has been a distinct change in increased frequency of heavy rainfall events, particularly in summer and autumn.
- CSIRO have simulated various climate models for the period from 2003-2030. In this period, the Bungendore region is expected to warm by $1.5\ ^0$C.
- CSIRO predict that for the period 2003-2030 there will be a tendency for less rain, with more summer rainfall in the region. The prediction for the Murray Darling Basin is for a 25mm decrease in average rainfall for the next 100 years.
- Predictions are that there will be an increase in the frequency of extreme events associated with climate variability: high temperatures, extreme rainfall, severe droughts, and wind storms.

# 10.0 GROUNDWATER AND OTHER MONITORING

Several existing bores located on Lake George have been geophysically logged, followed by the installation water level monitoring devices.

The work programme has allocated funds for the conversion of several existing test bores to monitoring bores in the Bungendore area. This work will be conducted in liaison with DIPNR, and in response to the conclusions reached in the generation of the groundwater model. The installation of data-loggers in the existing groundwater monitoring bores at Bungendore is considered necessary.

Rainfall data from the existing weather stations is considered adequate, and there will be no expenditure for this budget item.

# 11.0 SUMMARY AND RECOMMENDATIONS

The following summarises the main results and conclusions (refer also to *Section 1.0 Executive Summary*):

- The evaluation has concluded that the groundwater system is not under stress. However, groundwater modelling concludes that the current level of groundwater abstraction is close to the sustainable yield under the current climatic conditions. Expansion of the allocatable groundwater resource will require input from *DIPNR*. A presentation of the results of the study to Council, *DIPNR*, the community, strategic planners and stake holders is proposed.
- The investigation has been conducted collaboratively by experienced geoscientists from industry and the University of NSW Water Research Laboratory. A high standard of research and technology has been applied to generate the project results.
- The project has been conducted within with the designated budget, with some minor variances in the programme. The proposed ground follow-up of airborne geophysical anomalies is not necessary, as the airborne data is of high quality. Additional weather stations in the catchment are considered unnecessary, and associated allocated funds are proposed for the installation of borehole data-loggers, which will provide an improved management of the resource.
- A more regular (quarterly, rather than annual) reporting schedule of groundwater abstraction from irrigation bores is necessary.
- The investigation has been successful in providing an excellent database for a better understanding of the hydrogeological controls. The groundwater model can be modified and updated as additional data becomes available.
- The airborne (VTEM) geophysical survey has been successful in defining the main palaeo-valleys that will assist in the delineation of further resources.
- The impacts of ‘climate change’ in the region are subjective. However, the likely tendencies, based on CSIRO models predict that there will be a continuing increase in average temperatures by approximately $1.5^0$C over the next 30 years. In the same period, rainfall is expected to reduce slightly, but with an increase in summer rain, and an increase in ‘extreme’ events.

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# APPENDIX 1

# APPENDIX 2