DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

BLUE LAKE HYDROGEOLOGICAL INVESTIGATION PROGRESS REPORT NO 1 - ASSESSMENT OF AVAILABLE HYDROGEOLOGICAL DATA

REPORT BOOK 93/14

by

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Blue Lake Hydrogeological Investigation Progress Report No 1 - Assessment of available hydrogeological data

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The Blue Lake is a valued water resource for the City of Mt Gambier and there is increasing community concern regarding its longer term sustainable use. The lake is groundwater fed and there is known contamination of the unconfined aquifer in the vicinity of the lake.

Groundwater flow into the Blue Lake is predominantately from the unconfined aquifer via an upper bryozoal sub-aquifer, a lower dolomite sub-aquifer and karstic features developed within the limestone. Some groundwater inflow is also derived from a deeper confined aquifer. It has not been possible to quantify the various groundwater inflow components due to a general lack of detailed hydraulic data.

A groundwater capture zone for the Blue Lake has been defined and this should be used to develop appropriate management policies to safeguard the water quality of the lake.

Stormwater discharge to the unconfined aquifer via naturally occurring karstic features and drainage wells in the Mount Gambier city area is likely to have resulted in some improvement in the lake's water quality.

A local decline in groundwater levels is most likely a result of the extraction of water from the Blue Lake and it is possible that the pumping rate has approached the volume of groundwater inflow into the lake.

Additional investigations to quantify the components of the water budget for the Blue Lake are recommended.

INTRODUCTION

The Blue Lake provides the water supply to the city of Mt Gambier which has an urban population of approximately 21 500 (Fig.1). There is increasing community concern for the long term water quality of the Blue Lake. As the lake is hydraulically connected to the groundwater system, there is a potential that contaminated groundwater within the unconfined aquifer could flow into Blue Lake and have a deleterious effect on the water quality.

The Mt Gambier region has had a long history of pollution of the unconfined aquifer (Harvey 1979, Smith 1980, Schrale et al 1984, Richardson 1990). This is due to the karstic nature of the aquifer and the permeable soils. Pollution has come from industrial sources including timber treatment plants, cheese factories, abattoirs, as well as agricultural pollution from animal husbandry. In the Mount Gambier city area, domestic sewerage was piped into underground pits causing groundwater contamination until the construction of the sewerage system in the 1960's. The groundwater contamination is reflected in the water quality of the unconfined aquifer where in many cases nitrate levels are greater than 45 mg/l (ie above AWRC - NHMRC guidelines). The major challenge in management of the water resource is to ensure that polluted groundwater does not recharge the Blue Lake.

A pre-requisite for effective management of the water resources of the Blue Lake is an understanding of the nature and amount of recharge into the lake. The lake is groundwater fed but estimating recharge is complicated by the karstic nature of the unconfined aquifer that surrounds the Blue Lake.

This report focuses on the groundwater flow regime surrounding the lake and potential zones for groundwater inflow. Previous workers have estimated the amount of groundwater inflow and the origin of the water from isotopic and geochemical techniques (Turner 1979, Turner et al 1983 and Ramamurthy 1983). This report builds upon previous work done in the region as well as examining new and existing data to provide a geological and hydrogeological framework from which a groundwater catchment zone of the Blue Lake is defined. Also the role of stormwater drainage recharging the Blue Lake is examined.

GEOLOGY

GENERAL

The study area is located within the Gambier Embayment of the Otway Basin. The Gambier Embayment is bounded to the north by outcropping granitic basement of the Padthaway Ridge and to the east by the Dundas Plateau, while to the northeast it is bound by the Murray Basin. The Otway Basin consists of a mixed sequence of marine and terrestrial deposits which were formed during the separation of Australia and Antarctica. A geological map of the study area is shown in Figure 2 and geological cross-sections are shown in Figure 3 A-C.

The geological units discussed in the text include Cainozoic sediments of the Dilwyn Formation, Gambier Limestone, Bridgewater Formation and Holocene volcanic deposits, which all have a nearby spatial distribution with the Blue Lake.The major structural features in the region, particularly the Tartwaup Fault, are related to rifting and post-depositional tectonics which have imposed a northwest-southeast structural trend through the region.

VOLCANICS

Volcanic deposits in the area form a part of the most recent activity in Australia. This last phase of volcanic eruption was dated at approximately 5000 years before present (Sheard 1980), although more recent work on dating of lake floor sediment suggests an age of at least 20,000 years before present (Leaney et al.1993 in prep).

The Mount Gambier volcanic complex has undergone two closely spaced periods of eruptive activity, each with a distinctive style. Initial eruptions occurred at the western end of the complex and resulted in small low open explosion craters. Second period eruptions were on a much larger scale and the explosions from this phase produced the large open craters seen today, one of which is the Blue Lake (Sheard 1978).

Volcanic deposits comprising tephra, basalt and tuffeaceous material unconformably overlie Holocene and older sediments in the Mt. Gambier region (Sheard 1978).

BRIDGEWATER FORMATION

The Bridgewater Formation contains calcareous sandstones, highly fossiliferous in part which can be unconsolidated to highly indurated. The Bridgewater Formation was formed during marine transgressions and regressions and represents stranded beach dunes (Sprigg 1952), with each ridge representing a paleoshore line related to Pleistocene sea level stands. Dunes are oriented in a northwest to southeast direction and disconformably overlie the Gambier Limestone.

GAMBIER LIMESTONE

Underlying the Bridgewater Formation is the Gambier Limestone. The Gambier Limestone is continuous throughout the region and contains a large variety of fossiliferous and calcareous deposits. The formation was deposited in an open shallow marine platform environment (McGowran 1973, James & Bone 1989). The Gambier Limestone has been divided into two distinct lithological units within the Mt Gambier region, an upper bryozoal unit and a lower dolomite/calcite unit.

Bryozoal Limestone Unit

The bryozoal limestone sub-unit of the Gambier Limestone is cream to grey, highly fossiliferous predominately bryozoal with minor brachiopods and mollusca. The unit is generally consolidated, particularly at or near the surface. Minor constituents include marl, flint, dolomite and glauconite.

The structure contour plan of the top of the Gambier Limestone **(Fig 4)** indicates a gentle deepening from 50m AHD (Australian Height Datum) in the north to 30m AHD south of the Blue Lake. The near-uniform dip and lack of disruption of the top of the Gambier Limestone infer that either major faulting of the upper part of the sequence has not occurred, or there has been widespread erosion of the upper limestone sequence. However other evidence from seismic data indicates that faulting has diminished towards the top of the Gambier Limestone (D.Cockshell per. comm.)

However, the Gambier Limestone isopach **(Fig 5)** indicates that at least part of the lower sequence has been affected by tectonic activity. The formation is thin in the north-west (near the outcrop of the Dilwyn Formation) and thickens towards the east and south to be in excess of 200 metres south of Blue Lake. Superimposed on this pattern is a series of northwest to southeast trending troughs and ridges which probably represent segments of upthrow and downthrown fault blocks.

Dolomite/Calcite Unit

The dolomite/calcite unit immediately underlies the bryozoal limestone unit. It contains grey, translucent to pink rhombic calcite and dolomite, with minor bryozoal limestone and marl interbeds. As both dolomite and calcite crystals are rhombic, identification can be difficult although the dolomite often tends to be orange/pink in colour. The top of the dolomite sequence can be indurated and can be recognised by a spike on the geophysical well log. The dolomite can also be friable and have a saccharodial appearance.

The dolomite cropsout 5 to 6 kilometres to the west of Mt. Gambier where it has a yellow to red friable appearance, and extends as far south as Port MacDonnell but is absent to the north of the Tartwaup Fault. A large number of drainage wells completed in this unit has allowed good definition of the unit in the Mt Gambier city area. The structural contour plan of the top of the unit **(Fig 6)** shows that it deepens towards the east from approximately +15 m AHD on the western boundary of the city to -60 m AHD on the eastern margin of the city, which approximately corresponds to the base of the Blue Lake. There is a slight ridge in the surface of the dolomite/calcite zone, plunging south-east (in the city region) which is coincident with a ridge at the top of the Dilwyn Formation. Rapid deepening of the formation south of Blue Lake indicates faulting across the Lakes complex with trough development to the south.

Karstification

The South East of South Australia is a low relief doline and uvula karst area and the solution features are best developed in the essentially crystalline limestones of mid tertiary age (Marker 1975).

The Tartwaup Fault finds surface expression in a series of elongated deep dolines. To the south these occur in addition to the uvulas, dolines and caves, numerous cenotes or collapse dolines. These are thought to develop along the trace of major subsurface channels (Marker 1975).

Karst features have formed in the Gambier Limestone in the study area as a result of several factors. These include the nature of the limestone (weakly indurated and permeable), rate of water infiltration and depth to water table, (Marker 1975). This karst development has obvious surface expression in the form of cenotes, dolines and depressions. Some of these features lead to extensive lateral cavity development (eg Engelbrecht Cave).

These areas of karst development appear to have formed by preferential flow along joint planes (as distinct from porous media flow which is the usual form in the Gambier Limestone).

Karstification in the region is controlled by the fluctuation of the water table (Love 1992). As groundwaters are supersaturated with respect to carbonate minerals any dissolution must occur above the water table in the vadose zone. The fluctuations of the water table has allowed karst development to occur both above and below the present water table. Examples of such features include the Cave Gardens, Olympic Park, Crouch Street, Boandik Terrace, Umpherston Cave and Showgrounds sinkholes.

The area surrounding Blue Lake appears to have enhanced karst development which could be related to the nature of the volcanic eruption. The volcanic eruption was violent due to the presence of basaltic magma interacting with groundwater which acted as a hydrothermal fluid. (Sheard 1978)

As the volcano erupted the magma chamber was partially dewatered. The chamber would then be filled by surrounding groundwater which would result in cooling of the chamber until the build up of pressure and temperature in the vent caused a explosion again. This process was most likely repeated a number of times and could be considered analogous to surging a well. This would have the potential for enhancing any karstic development locally in the region, and it is possible that in the Mount Gambier region to have interconnected, previously separated karst features.

DILWYN FORMATION

The Dilwyn Formation comprises a series of unconsolidated sandstone and gravels with carbonaceous clay interbeds. The formation was deposited in a fluvial deltaic environment (Holdgate 1981). The sequence thickens south of the Tartwaup Fault reaching a maximum of 818 metres near the coast, as shown in oil exploration well Kentgrove 1 (Gravestock et.al.1986). The formation cropsout 7 kilometres northwest the city at Allens Quarry.

A structure contour plan of the top of the Dilwyn Formation (Fig. 7) was prepared from both private and Departmental drilling records. This indicates deepening of the formation towards the east and south. Superimposed on this general pattern is a series of northwest to southeast trending troughs and ridges. Although not presented on the plan, these troughs and ridges are probably steep sided and correspond to faulting in the region together with post depositional erosion. The rapid deepening of the formation from north to south across Blue Lake corresponds to a major fault across the Lakes complex.

STRUCTURE/TECTONICS

The Otway Basin was deposited on a passive continental margin associated with rifting and break-up of the Australian-Antarctic palaeocontinent.

There appears to be an overall northwest to southeast trending structural grain as is evident by the orientation of faults, sand dunes, troughs and ridges, as well as lineaments throughout the region (Fig 2).

A large number of growth faults has developed in the region due to rapid deposition of prograding deltaic depocentres which have since been subject to post-depositional faulting.

Some of the major structural elements in the region include:

Beachport - Kalangadoo Structural High

This structural entity occurs in the northern portion of the study area in the Dismal Swamp - Mingbool region, which has undergone significant truncation and erosion of the Tertiary sequence and has been a focus for gentle upwarping. These factors have resulted in thinning of the Gambier Limestone and elevation of the Dilwyn Formation to near surface.

Tartwaup Fault

The Tartwaup Fault is a major northwest to southeast trending fault that acts as a depositional hinge line with Cretaceous and Tertiary sediments rapidly thickening towards the south. To the north of the Tartwaup Fault, the Tertiary and Cretaceous sequence thin above the elevated Beachport - Kalangadoo High. The throw on the fault diminishes towards the surface and is expressed as a monoclinal flexure at the outcrop of the Dilwyn Formation at Allens Quarry (Waterhouse 1973, Kealing 1983) However, at depth the throw on the fault can exceed 500 metres (Gravestock et al 1986).

Blue Lake Fault Complex

The drilling of wells BLA 145 and BLA 146 (see **Fig 8** for location of observation wells) on either side of the Blue Lake has indicated a major fault occurring in the Mount Gambier volcanic complex with a throw of 79 metres from the top of the Dilwyn Formation (**Fig 3c**). The fault is probably associated with a dyke at depth and is a zone of structural weakness through which volcanic eruptive activity occurred.

HYDROGEOLOGY

GENERAL

Two regional groundwater systems occur within the region - an unconfined aquifer essentially contained within the Gambier Limestone and a lower confined sand aquifer of the Dilwyn Formation which are separated by an aquitard. The main hydrogeological units are described in Table 1.

The unconfined aquifer groundwater resources are used extensively through the region for domestic, stock, irrigation and industrial purposes. The groundwater resources of the confined aquifer are predominately used for municipal water supplies and limited other uses where groundwater is not readily available from the unconfined aquifer.

UNCONFINED AQUIFER

General

The unconfined aquifer occurs essentially within the Gambier Limestone and in some local areas within the Bridgewater Formation. Volumetrically the Gambier Limestone is the largest unit.

The aquifer has the characteristics of a dual porosity media with both primarily developed porous medium and secondarily developed karstic flow. This is reflected in the wide range of transmissivity values for the unconfined aquifer from 2 to 35 000 $m^3/d/m$ (**Fig 9**).

Natural recharge to the unconfined aquifer occurs via infiltration of rainfall through the unsaturated zone throughout the area. This can occur via a number of physical settings, but generally low evapotranspiration rates and permeable soil conditions result in low salinity water recharging the aquifer (Love 1992). Allison and Hughes (1978) have estimated this recharge to vary from 70 to 250 mm/yr according to variations in soil type. However under *pinus radiata* plantations recharge is considered to be minimal (Holmes and Colville 1970) with zero recharge beneath established mature pine plantations. Artificial stormwater recharge of the aquifer occurs within the Mt Gambier city area as there is no naturally developed surface drainage in the region. This aspect is discussed in more detail in a later section of the report.

Regional groundwater discharge occurs via coastal and offshore springs.

Sub-Aquifers

The Gambier Limestone unconfined aquifer in the Mount Gambier area can be differentiated into two sub-aquifers - an upper bryozoal limestone unit and a lower dolomite unit. This differentiation has been possible due to the available data from a large number of deep drainage wells drilled in the township area. Outside the Mount Gambier area, the relationship between the two sub-aquifers is not as well defined due to a general lack of drilling data.

TABLE 1: SUMMARY OF HYDROGEOLOGICAL UNITS

Hydrogeological Unit	Lithology	Comment
Gambier Unconfined Aquifer	Fossiliferous limestone with minor glauconite, flint and dolomite. Can contain groundwater within the Bridgewater Formation.	Regional unconfined aquifer, karstic with dual porosity medium. Forms two sub aquifers within the Mt Gambier city region an upper bryozoal unit and a lower dolomite/calcite subaquifer.
Upper Tertiary Aquitard	Marl at top, brown to black carbonaceous clay minor lignite and sand.	Regional confining bed, thin or absent within the Beachport-Kalangandoo High.
Dilwyn Confined Aquifer	Sand, gravel and clay interbeds.	Regional confined aquifer, porous medium flow.

The sub-aquifers have been defined essentially on their lithologies. The hydraulic relationship between the sub-aquifers is not precisely known due to a lack of detailed data for the dolomite sub-aquifer, but some degree of hydraulic interconnection can be assumed. A small hydraulic head difference between the sub-aquifers is indicated at one site but further investigations are required. A brief description of the sub-aquifers is provided below.

Bryozoal Limestone Sub-Aquifer

The sub-aquifer occurs within the bryozoal limestone unit of the Gambier Limestone (discussed previously).

Both porous medium and karstic groundwater flow are evident. Transmissivity values obtained from a number of short term pumping tests range from < 10m^3/d/m (indicative of predominant porous medium flow) to about 30 000 m^3/d/m which represents karstic flow. However the average values for transmissivity range from 300 to 500 m^3/d/m.

Dolomite Sub-Aquifer

This sub-aquifer occurs within the dolomite unit of the lower part of the Gambier Limestone (described previously).

The hydraulic characteristics are not well known due to a lack of any detailed aquifer tests. The preference, however, for many of the stormwater drainage wells to be completed in this sub-aquifer would suggest that at least moderate to high transmissivities exist.

Groundwater Movement

Regional groundwater has a potential to flow in a southerly and a south westerly direction towards the sea **(Figs 10 & 11)**. However on a local scale there can be a reversal of this pattern due to local flow systems or karstic terrains. Local flow systems are a result of the hummocky terrain imposed by the Bridgewater Formation. Highly karstic zones of the Gambier Limestone result in flat gradients where the potential groundwater flow direction is difficult to predict on a local scale.

To the north of the city on the Beachport - Kalangadoo structural high, the water table has a relatively flat gradient of 1 x 10^{-3}. This zone corresponds to thinning and elevation of the unconfined and confined aquifers near surface. Local groundwater flow cells have been recognised where there is a reversal of the regional groundwater flow direction towards a groundwater sink.

To the south of this zone there is a rapid change in slope of the hydralic gradient steepening up to 6.5 x 10^{-3}. The steep gradient zone is a result of a reduction in transmissivity which may be a result of decreased permeability or a reduction in aquifer thickness. The isopach of the Gambier Limestone **(Fig 5)** and cross-section A **(Fig 3A)** do not show any rapid thinning of the aquifer towards the north-east inferring that the change in transmissivity is due to a reduction of permeability. However, the steep gradient towards the north-west is a result of thinning of the unconfined aquifer.

To the south of the steep gradient zone, there is an increase in transmissivity as suggested by the flat gradient zone surrounding the Blue Lake. In this region, there is a large variation in hydraulic properties which is characteristic of karstic terrains. The lack of variation of the hydraulic gradient and the karstic nature of the aquifer have resulted in difficulty in predicting the groundwater flow directions.

To the south of the Blue Lake there is a local reversal of the regional groundwater flow direction towards the north-east. This corresponds to a groundwater divide below a dune ridge where there is a slight elevation of the water table. This feature is considered to represent a local flow system where discharge is focused towards the Lakes complex. Due to lack of deep penetrating wells in the dune high, the depth distribution of this reversal in gradient is not known. It is possible that at depth the groundwater flow direction would be coincident with that of the regional water table that is south westerly.

The September 1992 and March 1992 water table contours (**Figs 10 and 11**) are virtually identical. However there is evidence of a long term regional decline of the water table over the last 20 years (**Fig 12**). This decline is the result of a number of possibilities, including reduction in recharge, change in land use practices and the effect of pumping from the Blue Lake. Superimposed on (**Fig 12**) is the major land use in the region. On the eastern margin there is a correlation between a decline in the water table and *pinus radiata* plantation.

The decline in groundwater levels is shown by the graphs of water levels versus time for a number of observation wells as shown in Figures 13 and 14. The locations of these wells are shown in Figure 8.

Preferential Stormwater Recharge

The lack of naturally developed surface drainage in the Mount Gambier area has resulted in a large number of stormwater drainage wells being constructed. The locations of known drainage wells in the Mount Gambier area are shown in Figure 15, although it is pointed out that some of these wells may have been abandoned. The best estimate is that there are 350 active drainage wells in the city. In addition to these drainage wells, a number of karstic features (eg Cave Gardens) are also used for stormwater drainage.

As the initial volume of stormwater delivered to a drainage well or karstic feature can have a high pollution loading, this practice has the potential to contaminate the unconfined aquifer with a possible impact on the quality of the water in the Blue Lake. Emmett (1985), however, found that stormwater quality in the Mount Gambier city area was low in pollutants as well as salinity. Nevertheless, as karstic features can be inter-connected there still remains a potential for polluted stormwater to reach the Blue Lake.

Emmett (1985) estimated that 2800 ML of stormwater was discharged annually to drainage wells and karstic features. This was derived based on the rainfall data and an assessed paved area for the Mount Gambier city. Adopting a similar approach, but using the temporal increase in the paved area from 1969 to 1992 in the Mount Gambier area, suggests that the volume of stormwater recharge to the unconfined aquifer has increased by about 500 ML per annum over this period (see **Fig 16**). It is felt that this technique of assessing stormwater recharge must be considered as semi-quantitative, and more quantitative methods of assessment should be explored together with some field monitoring.

Apart from the potential to introduce contaminants into the unconfined aquifer, there are two other major potential impacts resulting from stormwater recharge. Firstly, increased localised stormwater recharge either into drainage wells or karstic features has the potential to mobilise groundwater pollution plumes. Secondly, should the stormwater have low concentrations of contaminants, the stormwater recharge will lead to an improvement in groundwater quality. Temporal water quality data for the Blue Lake (**Fig 16**), discussed in more detail later in this report, suggests that this is occurring.

Groundwater Quality

Groundwater is generally good quality low salinity water ranging from 300 - 600 mg/l throughout the region (**Fig 17**). The groundwater is characteristic of a calcium, sodium, bicarbonate type. Radiocarbon dating of groundwater from the unconfined aquifer indicates that recharge occurs throughout the region and has a relatively modern age.

The water table aquifer is susceptible to groundwater contamination as evident by the elevated nitrate levels in the region. Nitrogen compounds such as organic nitrogen and ammonia are readily oxidised to nitrate in the soil and are then leached by recharge to the aquifer. Alternatively where direct contamination of the aquifer by organic nitrogen and ammonia has occurred, oxidation to nitrate occurs more slowly. However the oxidation process is still relatively rapid in comparison with the groundwater residence time within the aquifer. Therefore because of this and the conservative nature of the nitrate ion, it is a good indicator of pollution within the region.

The Gambier Limestone is particularly prone to pollution due to its karstic nature lack of surface drainage, high rainfall of the region and the permeable nature of soils in the region. High nitrate levels ranging from 25 to 100 mg/l occur within the vicinity of the lake. Many wells have nitrate levels exceeding the recommended AWAC - NHMRC drinking limit of 45 mg/l nitrate. Nitrate versus depth of aquifer penetration **(Fig 18 a & b)** indicates that wells completed in the upper portion of the aquifer have variable concentrations ranging from 10 to 100 mg/l. Nitrate declines with depth to a mean of approximately 40 mg/l suggesting form of stratification. Waterhouse 1977 and Dillon 1988 have shown that groundwater quality may vary between stratified to well mixed, as would be expected in a dual porosity medium such as the Gambier Limestone.

There is some indication of low salinity and low nitrate water within the dolomitic sub-aquifer.

CONFINED AQUIFER

General

The Dilwyn Formation confined aquifer is not used extensively in the region. However, it does represent an important "back-up" groundwater resource for the unconfined aquifer due to its low salinity and general potable quality.

The confined aquifer contains a series of sand, gravel, clay and minor carbonaceous clay horizons. The spatial distribution of the Dilwyn aquifer is complex due to influence of tectonics. Reactivation of faults has resulted in disruption of the Tertiary units which has resulted in some cases with direct lithological and hydraulic connection between the Gambier and Dilwyn aquifers. The transmissivity of the aquifer varies from 300 to 600 $m^3/d/m$.

Groundwater Movement

There is a potential for groundwater to travel in a southerly direction towards the sea. Groundwater mounds occur to the north-east of Mount Gambier in the Mingbool and Nangwarry region. These areas correspond to where the Dilwyn Formation is elevated near the surface in the Kalangadoo Structural High region. The potentiometric gradient steepens towards the south coincident with the Tartwaup Fault. This is probably a result of either a reduction in permeability or more likely thinning of the aquifer towards the northeast. South of Mount Gambier the hydraulic gradient flattens towards the coast.

As the Dilwyn Formation only cropsout over a small area the bulk of recharge to the system must occur via downward leakage through the unconfined aquifer and confining bed. There is a potential for recharge to the Dilwyn aquifer to occur in the Kalangadoo Structural High region where the aquifer is elevated to near surface and the confining bed is thin. Recharge in this zone has been identified on the basis of high radiocarbon activities as well as a downward hydraulic head potential. (Love et al 1993).

There is a downward head and hence a potential for recharge to the Dilwyn aquifer from the structural high region to the hydraulic hinge line between the Gambier and Dilwyn aquifer (3 km north of Mount Gambier). At this location the hydraulic heads of both aquifers are the same. From this position the heads reverse and there is a potential for upward leakage from the Dilwyn to the Gambier aquifer. The confined aquifer head is between 10 and 20 meters higher in the vicinity of Blue Lake where there is a potential for upward leakage to the Blue Lake through the volcanic vent.

Groundwater Quality

The salinity of the confined groundwater is low ranging from 500 to 670 mg/l with a calcium, sodium, bicarbonate character. The water is also low in nitrate concentration ranging from 1 to 6 mg/l, and dissolved oxygen is low which results in anaerobic conditions. Degassing of hydrogen sulphide is also present in many wells.

Radiocarbon dating of the dissolved inorganic carbon in Dilwyn groundwaters in the vicinity of the township indicate a mean water residence time between 15 000 to 25 000 years. Groundwaters of this age were recharged during the last glacial period probably under a lower precipitation/evaporation regime as well as lower temperatures than today. This can in part explain the calcium, sodium, bicarbonate character of the water as well as the low total dissolved solids (Love et al 1993).

THE BLUE LAKE

GENERAL

The Blue Lake is one of a series of complex volcanic maars that have punctuated the Holocene/Pleistocene surface in southeastern Australia (Sheard 1978). Blue Lake represents the most easterly crater within the Mount Gambier volcanic complex. Groundwater was the major hydrothermal fluid with water vapour being the main gas.

The water level in the Blue Lake has shown a gradual decline over the last 70 years as shown in Figure 19. There was a rapid increase in the extraction rate from the Blue Lake (**Fig. 19**) from about 1950 which corresponds to the increased development of the Mount Gambier city region. The increased pumping from the Blue Lake is most likely to be the major cause for the decline in the lake water level.

Since the mid-1970's, extraction rates have plateaued but this is not reflected in the Blue Lake water levels which have continued to decline.

The graph of cumulative deviation from the mean rainfall (**Fig. 19**) suggests some correlation with the Blue Lake water level, but the major impact is considered to be the pumping from the Blue Lake.

The lake is the reticulated water supply for Mount Gambier with total dissolved solids around 360 mg/l. The bathometry indicates it has an almost flat bottom and a depth of approximately 70 metres (Tamuly 1970). The Blue Lake can be considered to represent an open "window" into the unconfined Gambier Limestone aquifer. The unconfined aquifer and Blue Lake have good hydraulic connection as is indicated by the coincidence of the water level of Blue Lake and well BLA 121 which is completed within the unconfined aquifer 30 metres from the northeast rim of the lake, as shown in Figure 13.

GROUNDWATER CAPTURE ZONE

On the basis of the water table configuration and hydraulic characteristics a potential groundwater capture zone for the Blue Lake has been defined (**Fig. 20**).

The groundwater capture zone is bounded to the south-west by the groundwater divide beneath the dune ridge. The capture zone continues almost to the State Border in a south-easterly direction as is defined by the configuration of the water table. The capture zone extends towards the north east as indicated by the water table contours.

There is a potential for groundwater anywhere within the capture zone to recharge the Blue Lake, however it must be noted that not all groundwater in this zone will flow directly into the Blue Lake.

The potential inflow from the volcanic lakes complex towards Blue Lake is considered to be minimal because of a lack of hydraulic connection. Volcanic deposits in the region have a low permeability (ranging from 1 x 10^{-1} to 7 x 10^{-3} m day^{-1}, Smith 1980) which would restrict groundwater movement. Valley Lake also represents a window into the unconfined aquifer, however its salinity of 900 mg/l is twice that of the Blue Lake. This is probably a result of the influence of evaporation in concentrating ions in this shallower water environment as well as the restricted throughflow. Therefore the two lakes are considered to have restricted hydraulic connection between them.

As the confined aquifer has a higher hydraulic head than the unconfined aquifer in the vicinity of Blue Lake there is a potential for upward leakage through the volcanic vent. Post depositional faulting has resulted in the potential for direct hydraulic connection between the unconfined and confined aquifers. This occurs along the Tartwaup Fault where the confined aquifer is possibly directly recharging the unconfined aquifer (as evident by cross-section

A, **Fig 3a**). Faulting to the north of the lake may also act as a zone of direct connection between the two aquifers. Anywhere direct connection occurs there is the potential for low nitrate groundwater from the confined aquifer to recharge the unconfined aquifer with the potential of this groundwater to ultimately recharge the Blue Lake.

WATER QUALITY

The lake is thermally stratified in summer with the development of a thermocline in November which becomes progressively deeper until April/May when complete mixing occurs (Tamuly 1970). This results in any incoming groundwater signature being masked for at least part of the year. A detailed analysis of water quality/depth data for the Blue Lake may indicate zones of preferential groundwater inflow into the lake.

Nitrate concentrations in the lake have increased from 12 mg/l in 1970 to 16 mg/l in 1979 and since then the nitrate concentration has plateaued (**Fig 16**). The change in nitrate concentrations with time is thought to be related to different physical mixing regimes or biological activity. Geochemical control on nitrate is unlikely in the upper portions for the lake as it is relatively conservative in an oxidising environment. However it is possible that biological activity could have an effect of nitrate levels under anaerobic conditions (ie denitrification). However the rate and mechanism of any such activity is beyond the scope of this project.

This increase in nitrate concentrations in the 1970's could be a result of increased inflow from the unconfined aquifer as a result of increased pumping in summer.

The lake has shown a gradual decline in total dissolved solids, chloride and sodium since the early 1970's (Telfer 1993) and as shown in Figure 16. Chloride can be considered to be conservative in both the lake and surrounding groundwaters and therefore is an excellent tracers of the mixing of different salinity recharge waters in the lake. The data clearly indicate that the lake water is mixing with a lower chloride water source.

If it is assumed that biological activity has not modified the nitrate concentration in the Blue Lake, then the cause of these water quality trends in the Blue Lake must be mixing with a lower chloride and lower nitrate water body. The potential end members for this mixing include the unconfined and confined aquifers as well as stormwater recharge.

The confined aquifer has low nitrate concentrations and because of this was previously considered to be a major contributor to the Blue Lake water budget. However, the chloride concentration in confined wells nearby the lake is higher (150 to 168 mg/l) than those of Blue Lake (85 mg/l). Therefore it is considered that the confined aquifer is making little contribution as mixing with a more concentrated end member will not produce a dilute mixture.

The chloride concentration within the unconfined aquifer nearby the lake is extremely variable (55 to 277 mg/l), therefore it is difficult to assign a characteristic end member concentration. The nitrate concentrations nearby the lake are also variable (an average of 70 mg/l under the city and 30 mg/l to the south of Blue Lake) but generally higher than the Blue Lake, indicating at least some additional water sources.

The most likely reason for the temporal water quality change in the Blue Lake is a result of increased mixing with stormwater recharge. Stormwater recharge meets both of the above criteria, low nitrate and low chloride concentrations.

The decline in chloride concentrations observed within the lake is a result of increased stormwater recharge to the unconfined aquifer and eventually recharge to Blue Lake. However it should be noted that the decline in chloride in Blue Lake observed today is a result of stormwater recharge in the past. This is due to the associated time lag between water recharging the unconfined aquifer and ultimately recharging Blue Lake. Considering the increase in the paved area of the city in the last 20 years it is most likely that the lake will continue to show a decline in chloride concentrations in the future.

WATER BUDGET COMPONENTS

The water budget of a groundwater fed lake such as Blue Lake can be described by the general equation below and Figure 21.

$$\Delta S = \Sigma I - \Sigma O$$

where ΔS = change in lake water storage
ΣI = sum of all water inputs into the lake
ΣO = sum of all water outputs from the lake

The water inputs into the Blue Lake will include direct rainfall plus groundwater inflow.

There are many uncertainties in calculating the groundwater budget components in a karstic limestone aquifer. The region around the Blue Lake is highly karstic and the unconfined aquifer has a large variation in hydraulic properties. The extremely flat gradient zone makes it difficult to predict in which direction groundwater will flow. As a result, water budget or numerical techniques based on hydraulic data are not considered to be particularly reliable in this kind of environment.

For these reasons, two major studies have been previously conducted using environmental isotopes in both the groundwater and the lake to determine the water throughflow and water budget of the lake. Turner (1983) using, tritium ,deuterium, oxygen 18 and radiocarbon in both the groundwater and the lake calculated a groundwater inflow of between 5000 and 6500 ML per annum with approximately 80% of this water coming from the unconfined aquifer and 20% from the confined. Ramamurthy (1985) and Love (1992) found a distinct contrast between uranium concentration and uranium isotopes between the two aquifers. The relatively oxidising unconfined aquifer has higher uranium concentrations and activity ratios near secular equilibrium. In contrast, Dilwyn groundwaters are more reduced and uranium is relatively insoluble under reduced conditions therefore having lower uranium concentrations and higher activity ratios. Ramamurthy calculated the groundwater inflow to be 5000 ML per annum with approximately 85% coming from the unconfined aquifer and 15% from confined groundwaters.

With the majority of the groundwater inflow being from the unconfined aquifer, it is important to determine the sources of recharge to this aquifer. A schematic geological section (Fig 22) shows the various hydrogeological components of the Blue Lake water budget.

The major recharge sources are:

- direct infiltration of rainfall through the unsaturated zone in most of the area, apart from the paved areas in the Mount Gambier city area. This recharge would primarily be to the bryozoal sub-aquifer, except in areas where the dolomite sub-aquifer forms the upper part of the unconfined aquifer (such as in the western part of the study area).

- the preferential stormwater recharge within the Mount Gambier city area. This stormwater is directed into both the bryozoal sub-aquifer and the dolomite sub-aquifer. The relative contributions to each sub-aquifer are not known.

- the inflow of confined aquifer groundwater into the unconfined aquifer, in areas such as along the Tartwaup Fault where it is possible that there is direct hydraulic connection between the aquifers.

On the basis of these studies and the current pumping rate of 4000 ML per year, the outflow from the lake should be between 1000 to 2500 ML per year.

This indicates that the pumping rate is approaching that of the groundwater inflow. If we assigned an error of ±30% to the calculated groundwater inflow then there is a potential that groundwater outflow has ceased.

DISCUSSION

Because of a lack of hydraulic data for the different components of the unconfined aquifer system surrounding the Blue Lake, no quantitative assessment of the water budget is possible. However as a first order approximation, the groundwater velocity has been converted to a groundwater residence time for the different components of the unconfined aquifer; the upper bryozoal limestone, karstic features, and the lower calcite/dolomite sub-aquifer. This can be done by rearranging Darcy's Law to:

$$V = Ki/\theta$$

where v = groundwater velocity (m/d)
i = hydraulic gradient
K = hydraulic conductivity (m/d)
θ = porosity

and the groundwater residence time can be determined by the following

groundwater residence $= x\theta/Ki$

where x = distance

The hydraulic conductivity of the bryozoal unit and the karstic horizons was estimated from available aquifer test data. However as there is no reliable data for the dolomitic zone, a range in hydraulic conductivity values for a medium sand was chosen.

The groundwater residence times (Table 2) were determined for a distance of 2 kilometres away from the Blue Lake and shows the potential time scale for any recharge to the aquifer systems which flow into the Blue Lake. Of note is the relatively rapid residence time and potential impact that karstic zones can have on the Blue Lake.

The groundwater capture zone was determined on the basis of the water table configuration. Any groundwater within this zone has the potential ultimately to flow into the Blue Lake. As there are a number of known cases of groundwater contamination within this zone, including point and diffuse sources (Schrale et al 1984, Smith 1980, Richardson 1990) there is concern for the potential impact of these pollution plumes on the water quality of the Blue Lake. There are a number of potential problems with the monitoring, assessment and remediation of pollution zones in such a karstic limestone terrain which are related to the spatial distribution of permeability within the aquifer system.

AQUIFER UNIT	i	θ	K($mday^{-1}$)	v(myr^{-1})	Residence Times (yrs)
BRYOZOAL	1×10^{-4}	0.3	6 - 10	0.7 - 1.2	1600-2800
DOLOMITE	1×10^{-4}	0.3	20 - 60	3 - 7	300-700
KARST	1×10^{-4}	0.3	300 - 1000	40 - 120	15-50

TABLE 2 Groundwater residence times for units of the unconfined aquifer.

This report and Telfer (1993) have indicated that stormwater recharge is having an impact on the water quality of the Blue Lake. It appears that the magnitude of the stormwater recharge has increased with an increase in the pavement area of the city and there is a potential for this increase in recharge to impact on water quality of the Blue Lake. If the drainage water remains low in total dissolved solids and pollutants, then this should result in the continual improvement of groundwater quality in the lake. However a potential problem is that increased stormwater recharge has the potential to mobilise any pollution plumes under the city region.

The regional decline of the water table throughout the last 20 years in the Mt Gambier region results from a change in two mechanisms a change in land use practices due to establishment of *pinus radiata* plantations in the eastern portion of the study area and a pumping effect from Blue Lake. The decline in water levels around the lake is probably a result of extraction from the Blue Lake exceeding inflow.

CONCLUSIONS

An assessment of the available hydrogeological data for the Blue Lake and its environs has been undertaken because of the concerns regarding the longer term water quality of the lake.

From the assessment it is concluded that:

* The majority of groundwater inflow into the Blue Lake is from the unconfined Gambier Limestone aquifer.

* There are three components of the groundwater inflow from the unconfined aquifer; flow from an upper bryozoal sub-aquifer, a lower dolomite sub-aquifer and from karstic features developed predominately in the bryozoal unit. The inflow from these different sources cannot be quantified at this point in time.

* Groundwater flow from a deeper confined aquifer also makes some contribution to the Lake's water supply, either directly through the volcanic vent or indirectly by flow into the deeper sections of the unconfined aquifer in areas where there is hydraulic interconnection.

* Within the groundwater capture zone, a number of groundwater pollution plumes have been detected and these have the potential to impact adversely on the water quality of the lake. It is considered that the definition and remediation of at least some groundwater pollution plumes may not be totally successful due to the karstic nature of the unconfined aquifer.

* Preferential stormwater recharge to the unconfined aquifer beneath the Mount Gambier city area has resulted in some improvement in the Blue Lake water quality.

* A longer term decline in unconfined aquifer groundwater levels in the vicinity of the Blue Lake may indicate that water extraction from the lake has exceeded the groundwater inflow.

RECOMMENDATIONS

* The defined groundwater capture zone for the Blue Lake should be used for the development of appropriate management policies to protect the water quality of the lake.

* The Blue Lake is a valued water resource which is potentially at risk of becoming polluted from a number of groundwater sources. The prevention or minimisation of any future groundwater contamination within the Blue Lake groundwater capture zone should be rigorously pursued. This applies particularly to the use of stormwater drainage wells at industrial sites.

Further investigations are warranted to:

- quantify the contributions of groundwater inflow into the Blue Lake from the various zones of the Gambier Limestone aquifer and from the confined Dilwyn aquifer. Hydraulic parameters and groundwater quality data for the dolomite sub-aquifer are particularly needed

- determine the relative contributions of the stormwater recharge to the sub-aquifer of the unconfined aquifer

- determine the groundwater pollution potential of the stormwater recharge to unconfined aquifer

- define more fully (if possible) the impact of extraction from the Blue Lake on local groundwater levels. This should include the determination of any groundwater outflow at depth beneath the dune ridge to the south of the lake

- examine any longer term changes in groundwater quality in the area north of Mount Gambier by re-sampling the wells used in the 1972 water quality sampling programme.

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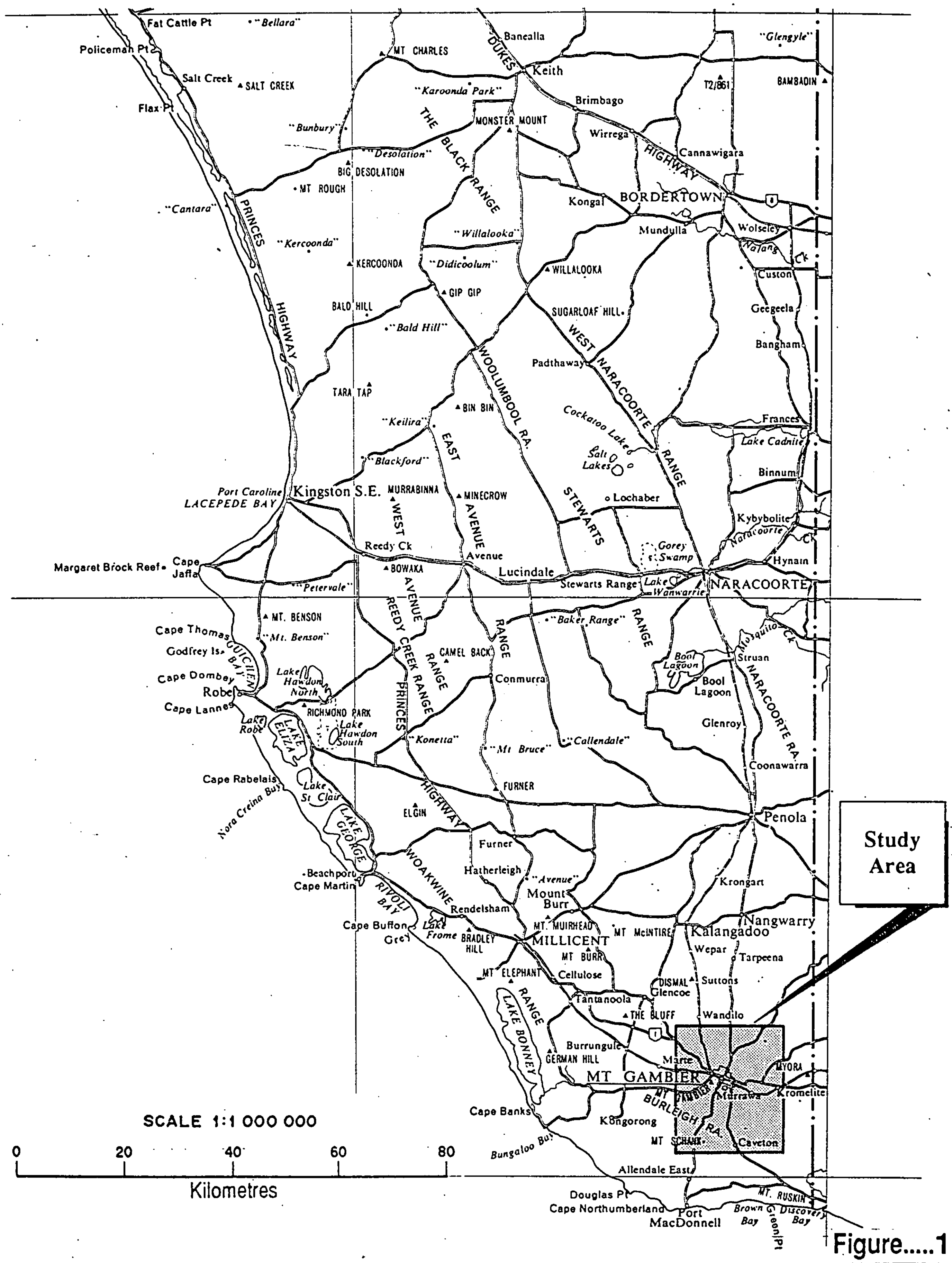
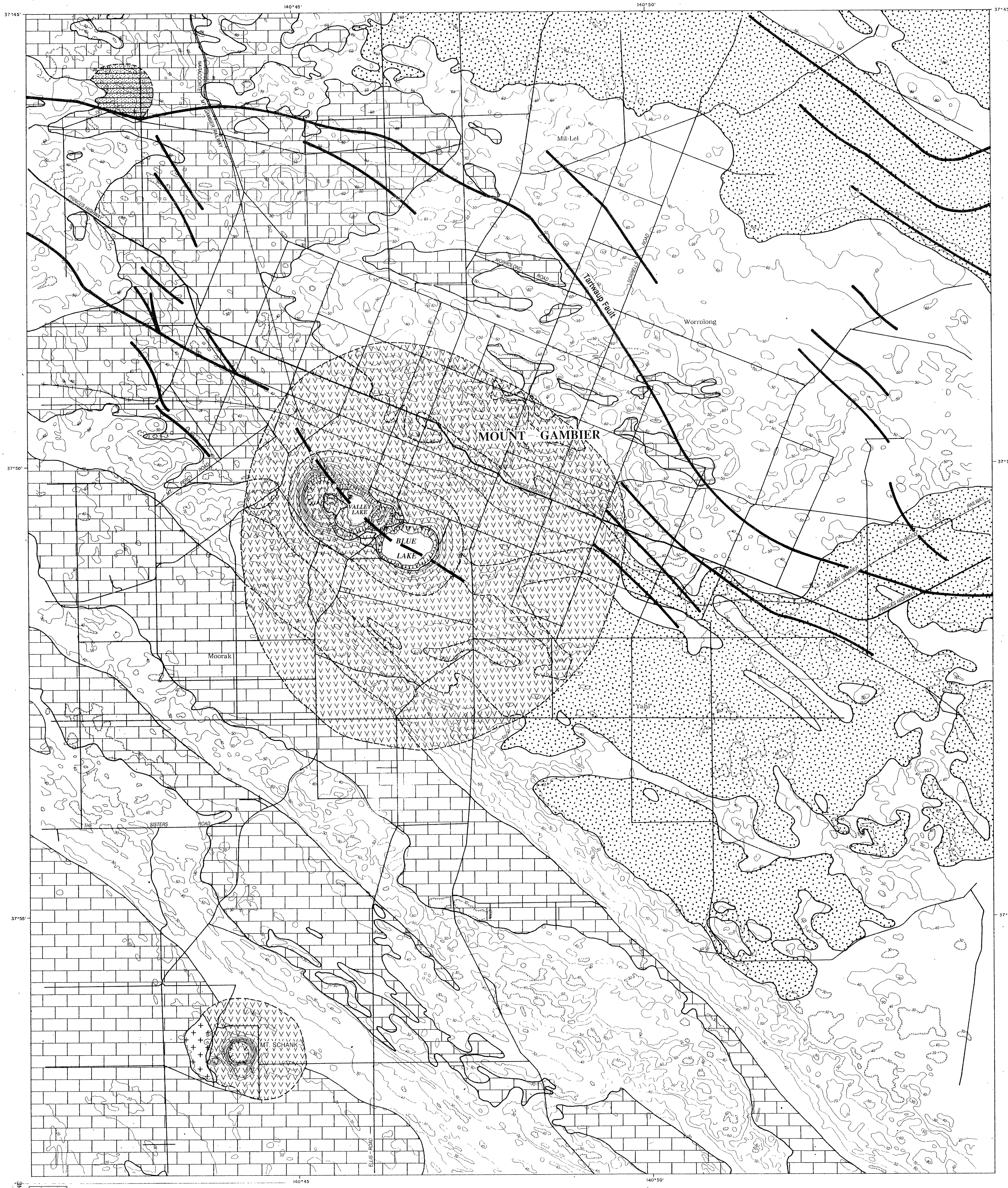


Figure.....1

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED J. Aslin	[signature] C.D.O.	6/4/93 DATE
BLUE LAKE HYDROGEOLOGICAL INVESTIGATION	DRAWN B. Donovan	SCALE As Shown	
LOCALITY PLAN	DATE Nov. 1992	PLAN NUMBER	
	CHECKED	**93 - 427**	

Job No. 5724



SCALE 1:50 000

METRES 1000 0 1 2 3 4 5 KILOMETRES

HOLOCENE — Deep meadow podsolic sands.

PLEISTOCENE — BRIDGEWATER FORMATION Aeolianite dune ranges.

Volcanic deposits, principally ash, lapilli, bombs and minor interbedded basalt flows.

Basalt, olivine basalt and scoriaceous basalt.

TERTIARY — GAMBIER LIMESTONE Bryozoal limestones and marls with flint beds and dolomitized zones.

DILWYN FORMATION Light coloured sands and clays with minor conglomerates and lignites.

LEGEND

.........Fault

.........Inferred Fault

.........Geological Boundary

.........Approximate Geological Boundary

Figure.....2

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

BLUE LAKE HYDROGEOLOGICAL INVESTIGATION

REGIONAL GEOLOGY

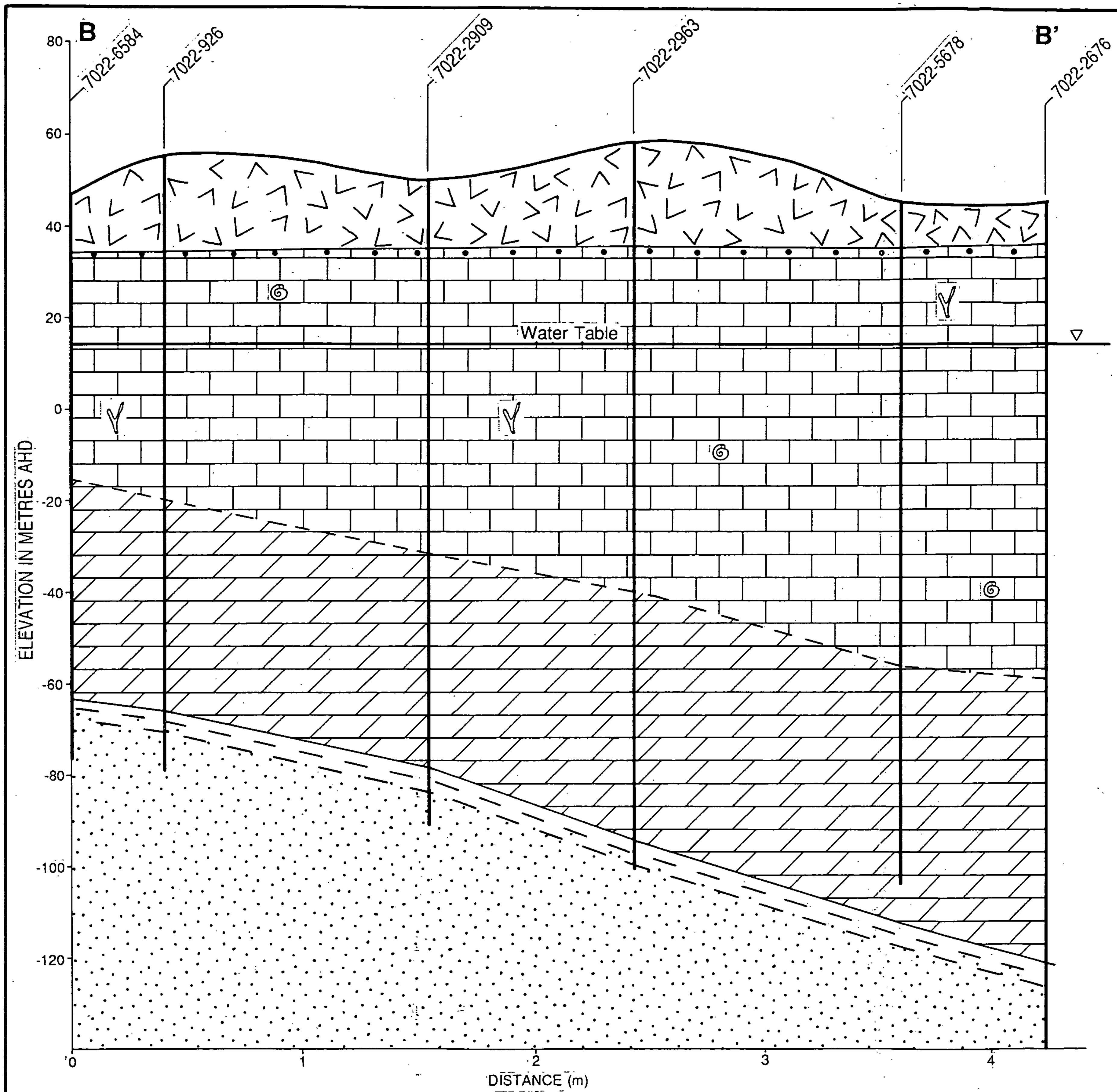
COMPILED	J. Lawson
DRAWN	B. Donovan
DATE	Nov. 1992
CHECKED	
C.D.U. / DATE	6/4/93
SCALE	As Shown
PLAN NUMBER	93 - 428

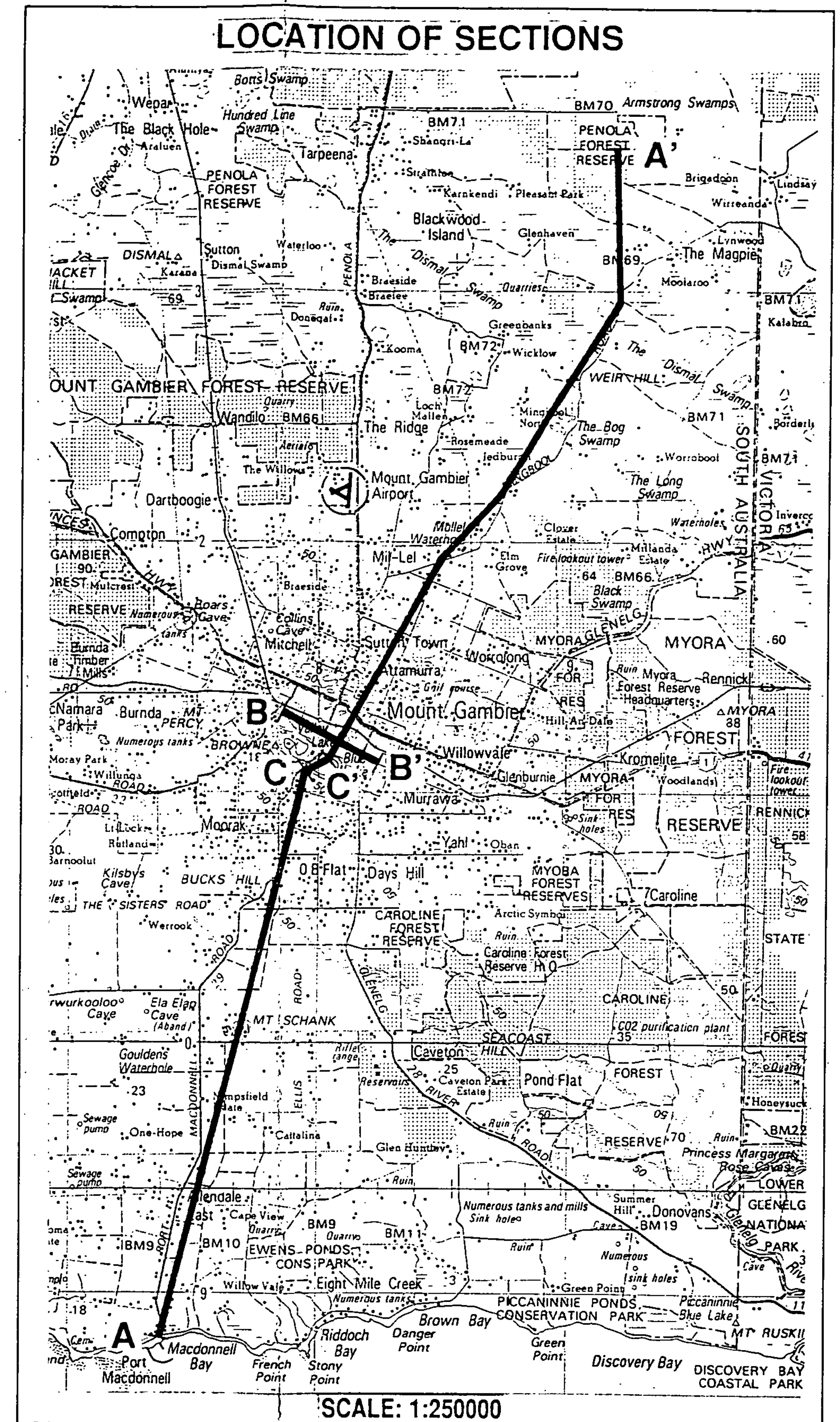
Job No. 5724

Figure.......3a

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED J. Lawson	C.D.O. 6/4/93	DATE
BLUE LAKE HYDROGEOLOGICAL INVESTIGATION	DRAWN B. Donovan	SCALE As Shown	
CROSS SECTION - PT. MACDONNELL TO MIN 21	DATE Feb. 1993	PLAN NUMBER	
	CHECKED	93 - 429	

Job No 5724





REFERENCE

- Volcanics
- Bridgewater Formation
- Bryozoal Limestone
- Dolomite
- Dilwyn Formation

SCALES: Horizontal 1 : 20000
Vertical 1 : 1000

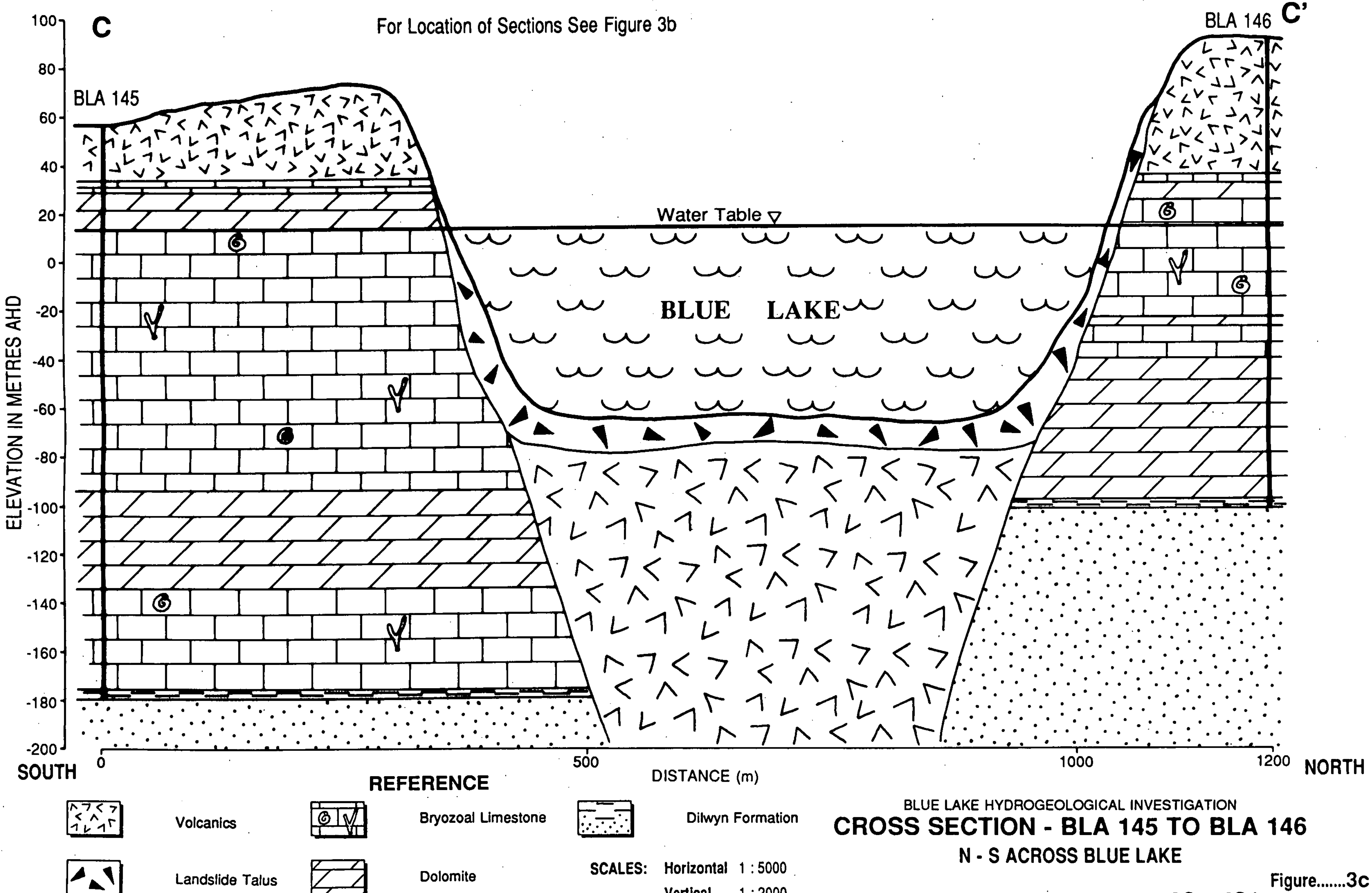
BLUE LAKE HYDROGEOLOGICAL INVESTIGATION

CROSS SECTION - 7022/6584 TO 7022/2676

Figure.......3b

SADME

93 - 430



BLUE LAKE HYDROGEOLOGICAL INVESTIGATION

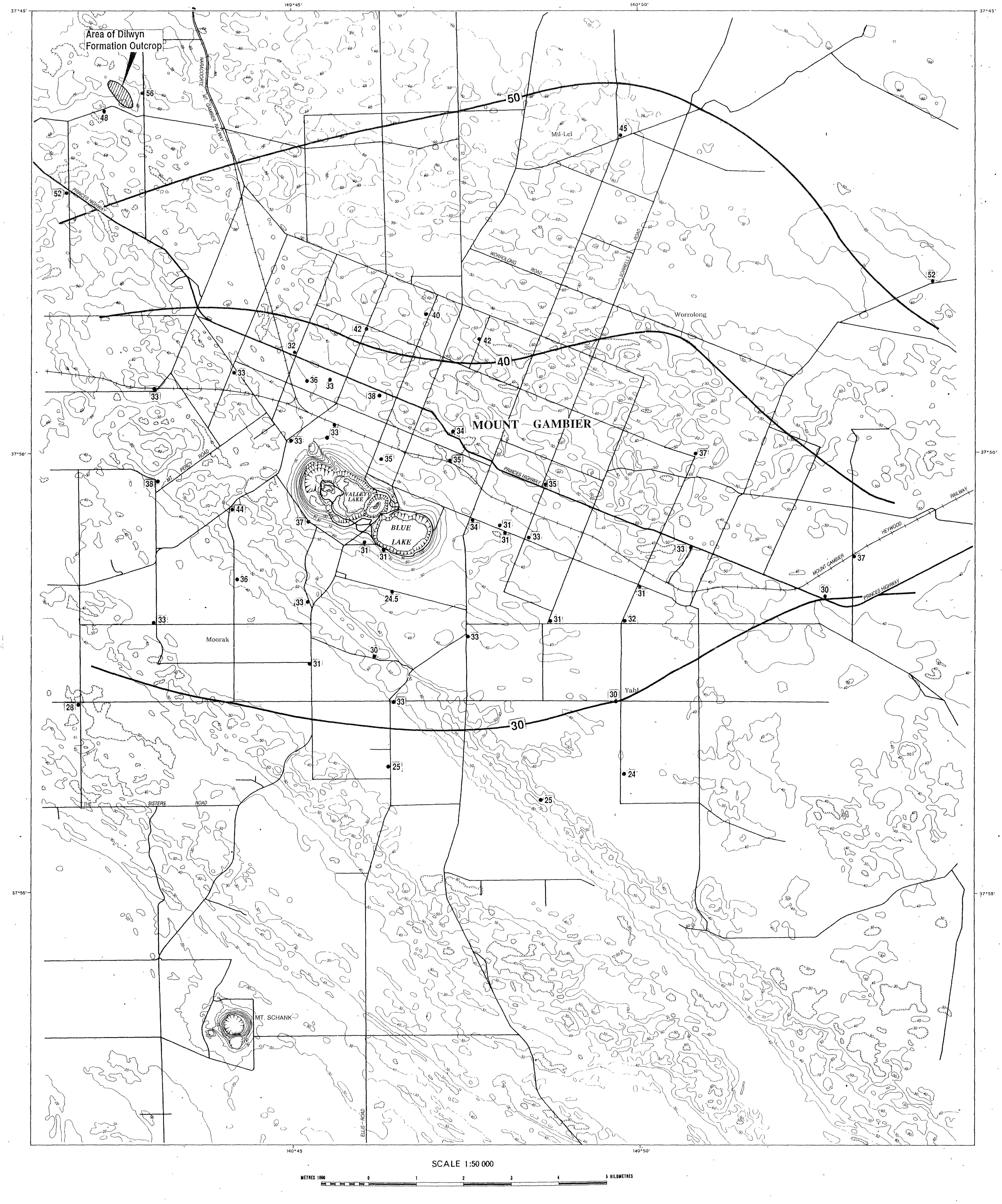
CROSS SECTION - BLA 145 TO BLA 146

N - S ACROSS BLUE LAKE

Figure.......3c

SADME

93 - 431



LEGEND

● ....Well with elevation of formation (m AHD)

—30—...........Structure contour (m AHD)

Figure.....4

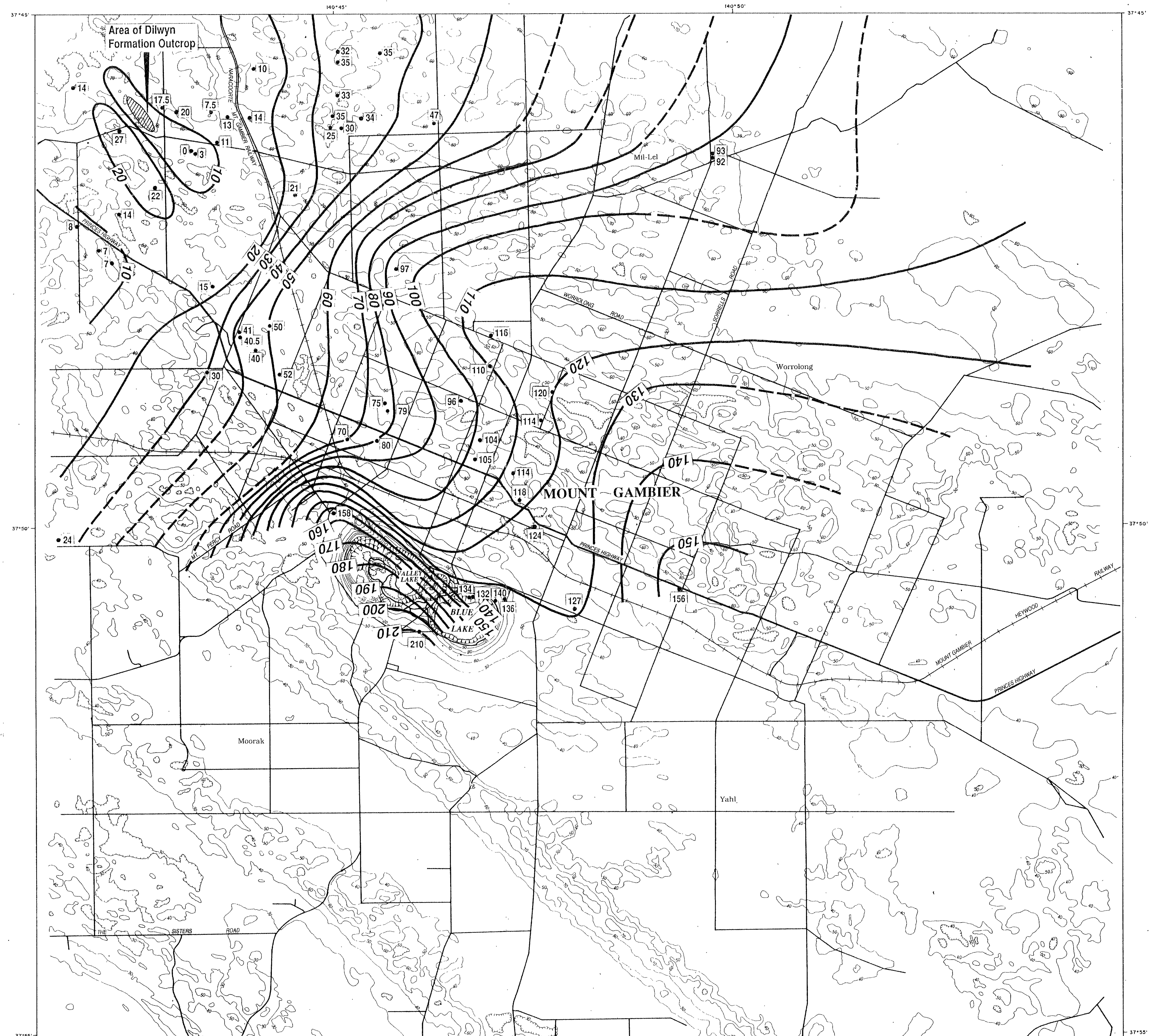
DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

BLUE LAKE HYDROGEOLOGICAL INVESTIGATION

TOP OF GAMBIER LIMESTONE STRUCTURE CONTOURS

COMPILED	J. Lawson
DRAWN	B. Donovan
DATE	Nov. 1992
CHECKED	6/4/93
SCALE	As Shown
PLAN NUMBER	93 - 432

Job No. 5724



SCALE 1:50 000

METRES 1000 0 1 2 3 4 5 KILOMETRES

LEGEND

—20— ....Isopach of Gambier Limestone (metres)

14 ● .... Thickness of Gambier Limestone (metres)

Figure.....5

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED J.A. & J.L.
BLUE LAKE HYDROGEOLOGICAL INVESTIGATION	DRAWN B. Donovan
	DATE Nov. 1992
ISOPACH OF GAMBIER LIMESTONE	CHECKED 6/4/93
	SCALE As Shown
	PLAN NUMBER 93 - 433

Job No. 5724

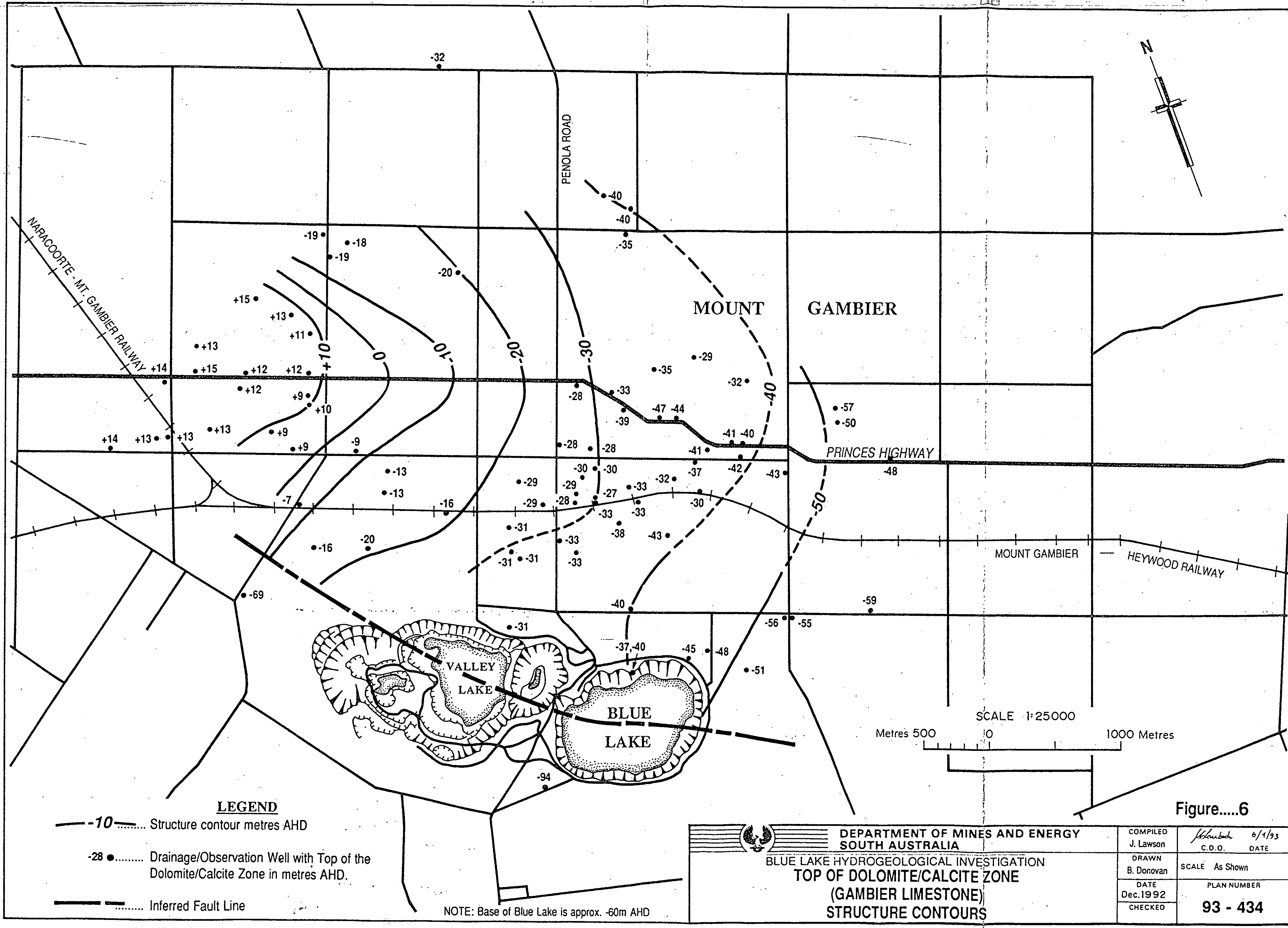


Figure.....6

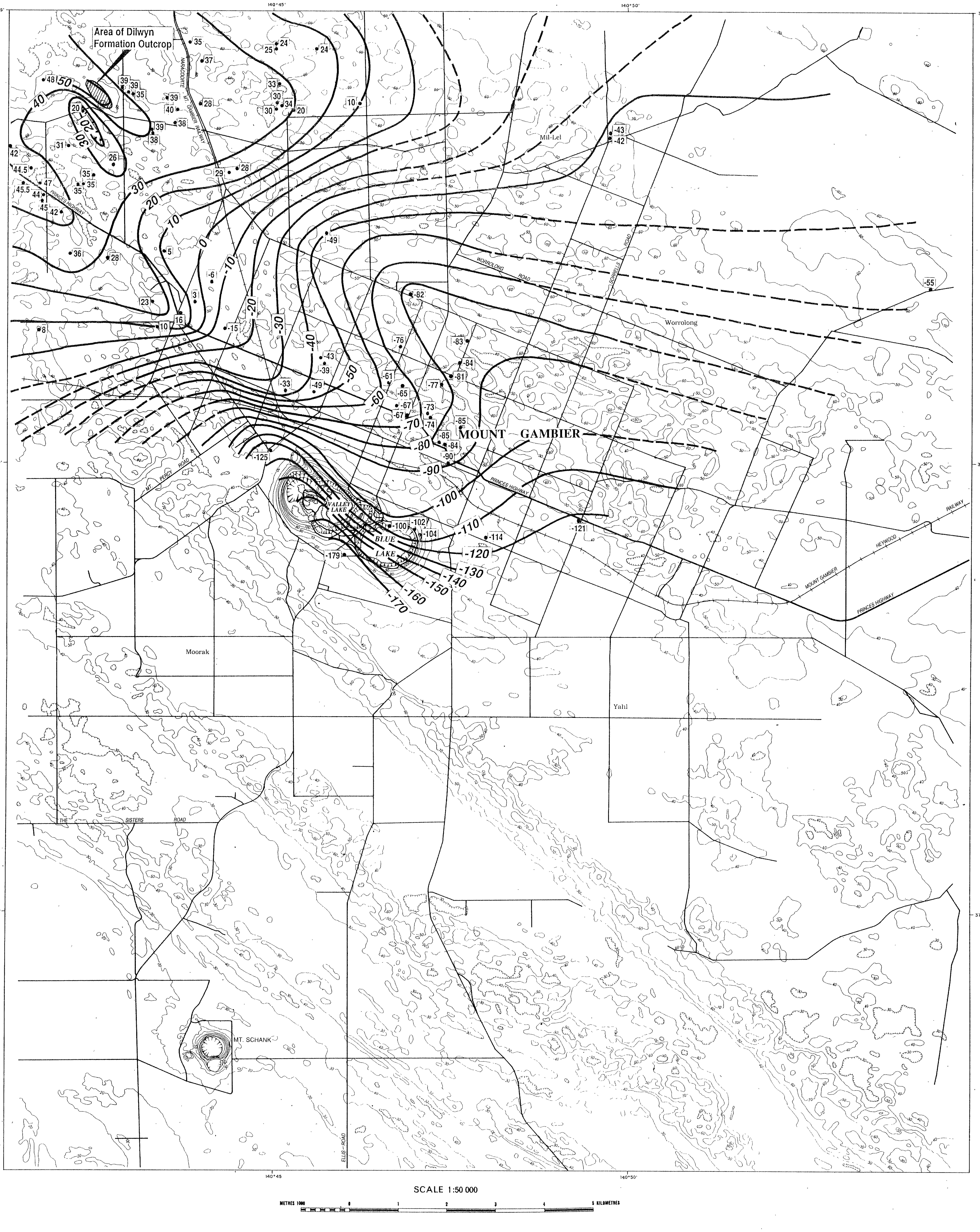
DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

BLUE LAKE HYDROGEOLOGICAL INVESTIGATION

TOP OF DOLOMITE/CALCITE ZONE (GAMBIER LIMESTONE) STRUCTURE CONTOURS

COMPILED J. Lawson	C.D.O.	DATE 6/1/93
DRAWN B. Donovan	SCALE As Shown	
DATE Dec.1992	PLAN NUMBER	
CHECKED	93 - 434	

Job No. 5724



LEGEND

20 ....Structure contour (m AHD)

114 ● ....Well with elevation of formation (m AHD)

Figure.....7

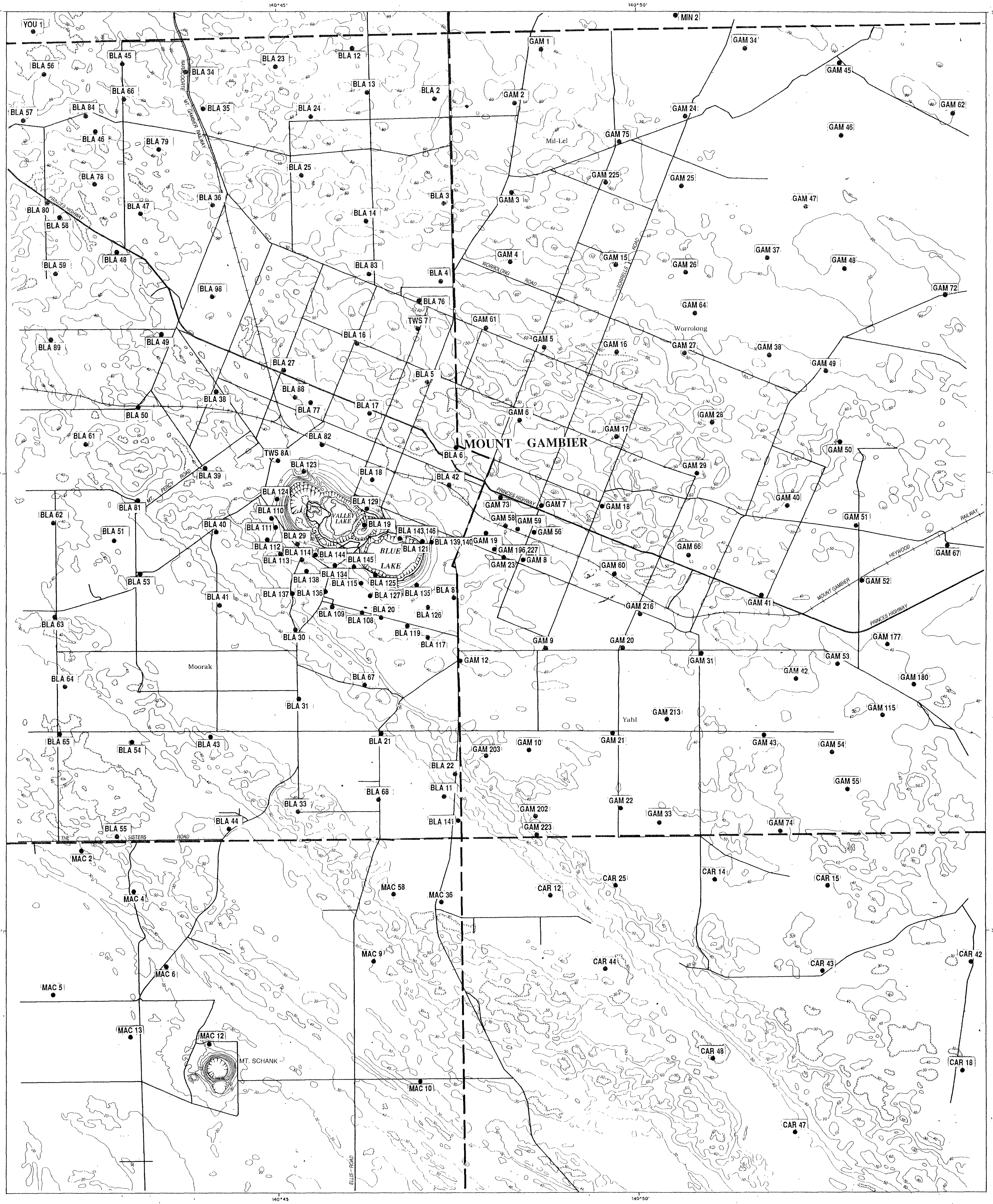
DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

BLUE LAKE HYDROGEOLOGICAL INVESTIGATION

TOP OF DILWYN FORMATION STRUCTURE CONTOURS

COMPILED	J.A. & J.L.
DRAWN	B. Donovan
DATE	Nov. 1992
CHECKED	
C.D.O. DATE	6/4/93
SCALE	As Shown
PLAN NUMBER	93 - 435

Job No. 5724



LEGEND

GAM 12 ●..................Observation Well and Number

Figure.....8

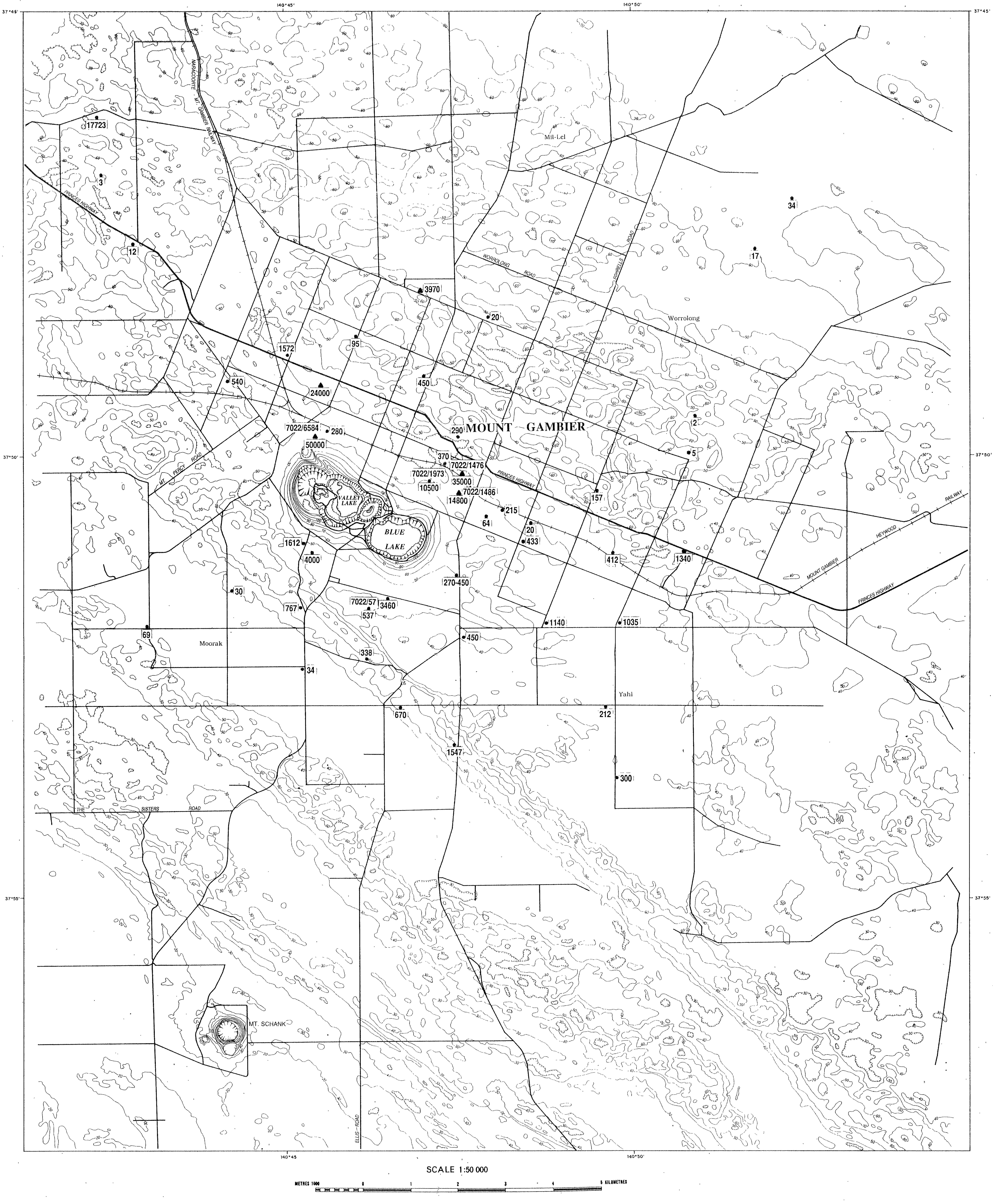
DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

BLUE LAKE HYDROGEOLOGICAL INVESTIGATION

LOCATION OF OBSERVATION WELLS

COMPILED	J. Lawson
DRAWN	B. Donovan
DATE	Nov. 1992
CHECKED	
C.O.O. / DATE	6/4/93
SCALE	As Shown
PLAN NUMBER	93 - 436

Job No. 5724



LEGEND

●................Observation Well
450................Transmissivity in m³/day/m
▲................Wells finished in the Dolomite/Calcite Zone
7022/1480................Well unit number

Figure.......9

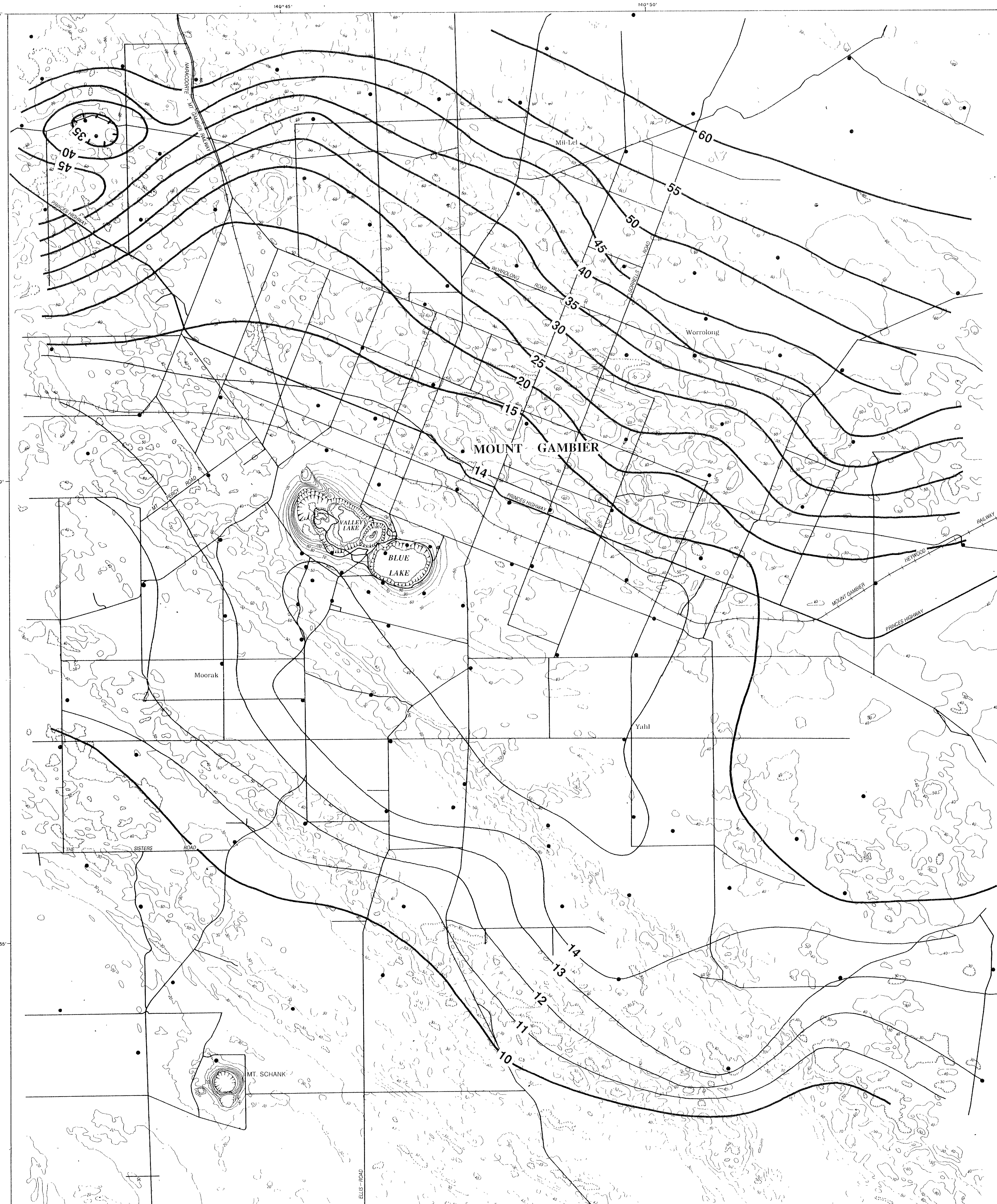
DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

BLUE LAKE HYDROGEOLOGICAL INVESTIGATION

UNCONFINED AQUIFER TRANSMISSIVITY VALUES

COMPILED	J.V.
DRAWN	B. Donovan
DATE	Nov. 1992
CHECKED	6/4/93
SCALE	As Shown
PLAN NUMBER	93 - 437

Job No. 5724



SCALE 1:50 000

METRES 1000 0 1 2 3 4 5 KILOMETRES

LEGEND

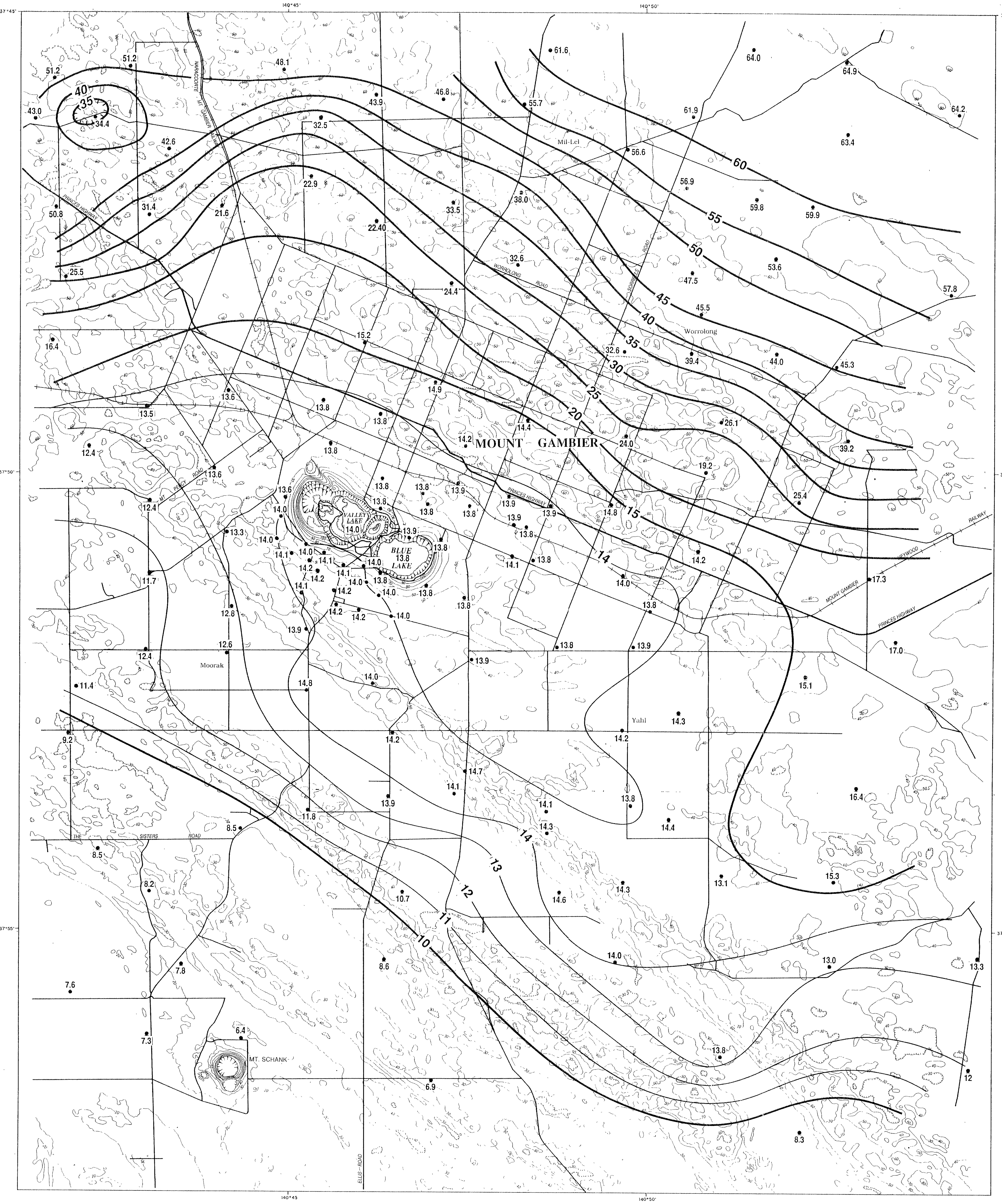
• .... Location of well used for water table measurements

—10— .... Potentiometric contour in metres.(AHD)

Figure.....10

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED J. Lawson
BLUE LAKE HYDROGEOLOGICAL INVESTIGATION	DRAWN B. Donovan
UNCONFINED AQUIFER	DATE Nov. 1992
WATER TABLE CONTOURS	CHECKED
MARCH 1992	SCALE As Shown
	PLAN NUMBER 93 - 438

Job No. 5724



SCALE 1:50 000

METRES 1000 0 1 2 3 4 5 KILOMETRES

LEGEND

13.8 •.................... Well with water level (m)

—10—.............Potentiometric contour in metres (AHD)

Figure.....11

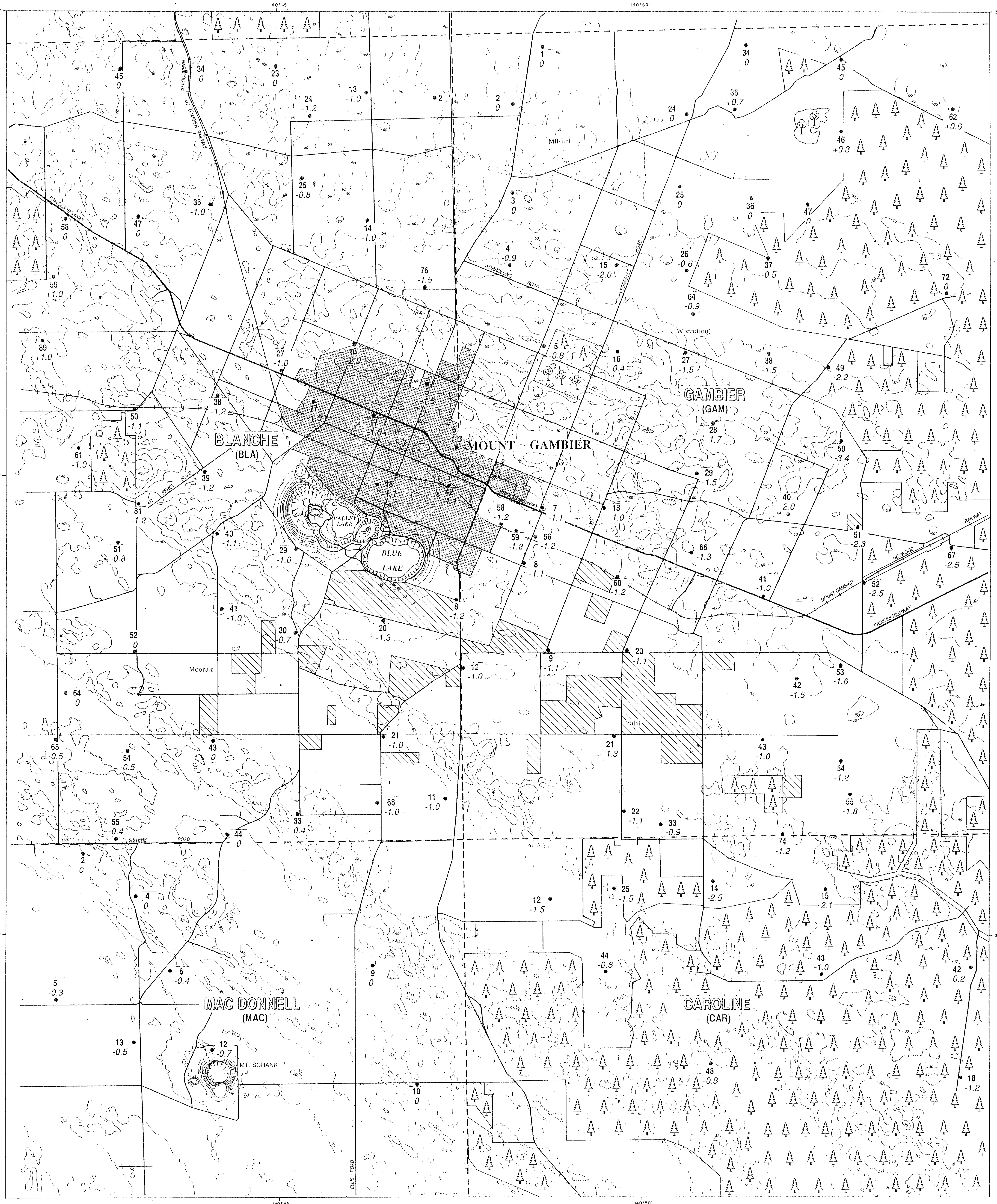
DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

BLUE LAKE HYDROGEOLOGICAL INVESTIGATION

UNCONFINED AQUIFER
WATER TABLE CONTOURS
SEPTEMBER 1992

COMPILED	J. Lawson
DRAWN	B. Donovan
DATE	Nov. 1992
CHECKED	6/4/93
SCALE	As Shown
PLAN NUMBER	93 - 439

Job No. 5724



Horticulture

Urban

Pine forest

Pasture

Native scrub

● 48 .... Observation well and number (prefix with hundred)

0.6 .... Change in water level (m) 1972-1992

NOTES: To obtain Obs. No. prefix well number with abbreviation for hundred
Land use derived from Dept. of Lands Topo/Cadastral - 1982

Figure.....12

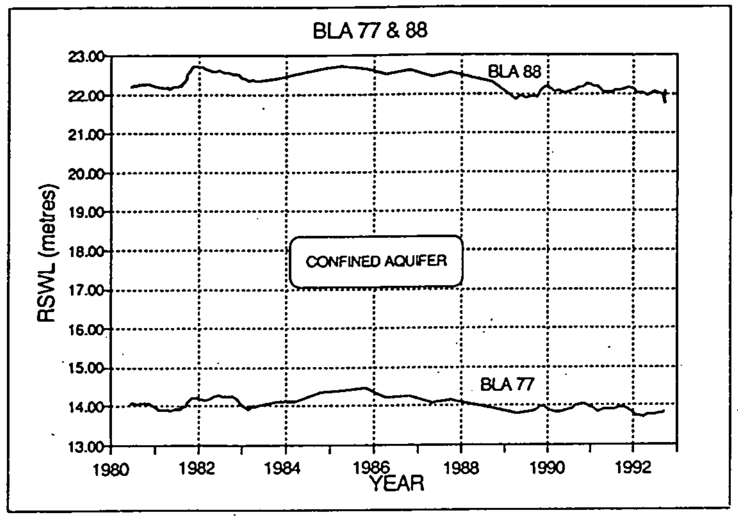
DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

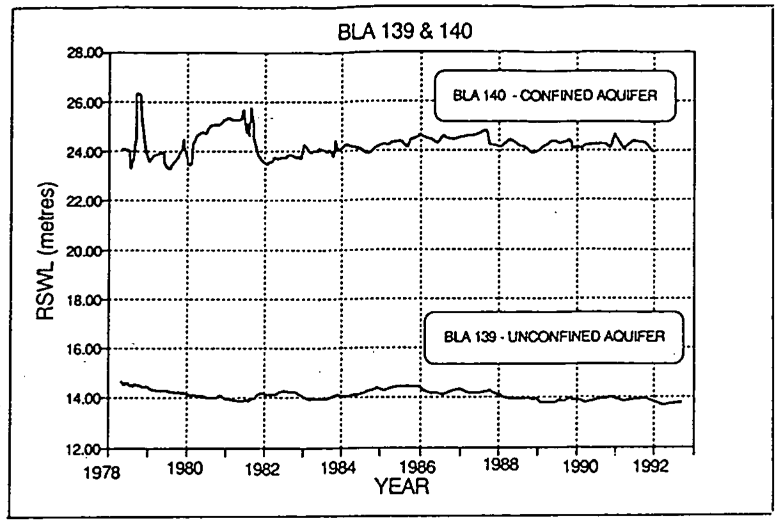
BLUE LAKE HYDROGEOLOGICAL INVESTIGATION

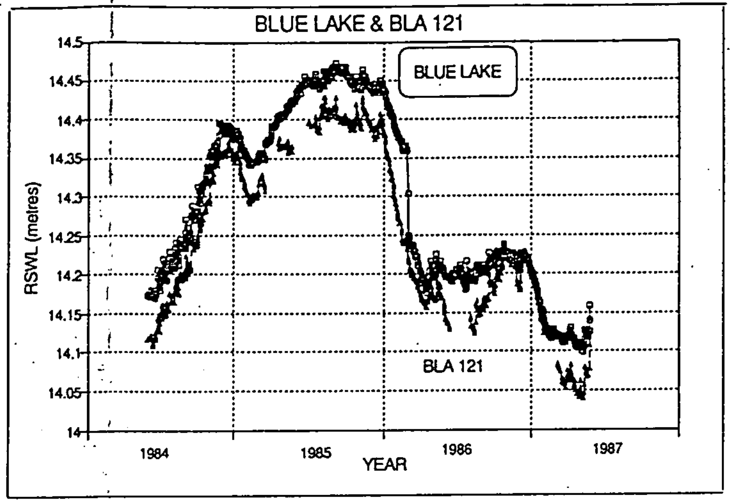
CHANGE IN WATER LEVEL AND MAJOR LAND USE

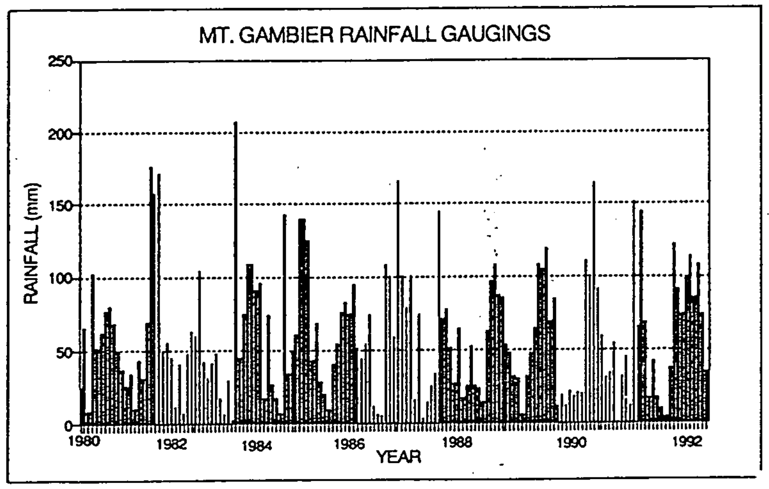
COMPILED	J. Lawson
DRAWN	B. Donovan
DATE	Jan 1993
SCALE	As Shown
PLAN NUMBER	93 - 440

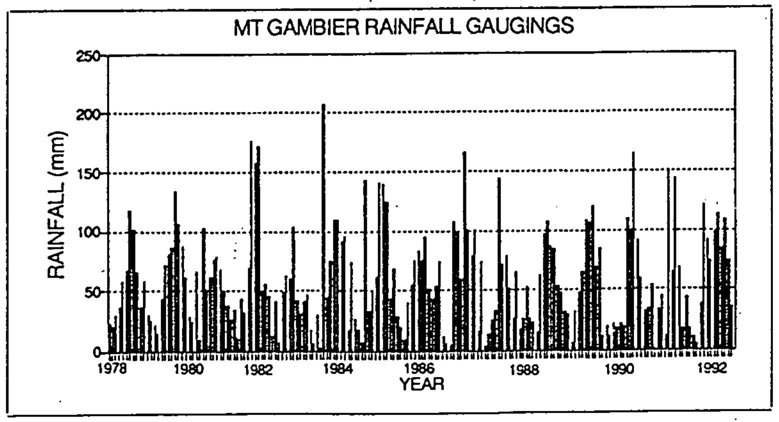
Job No. 5724











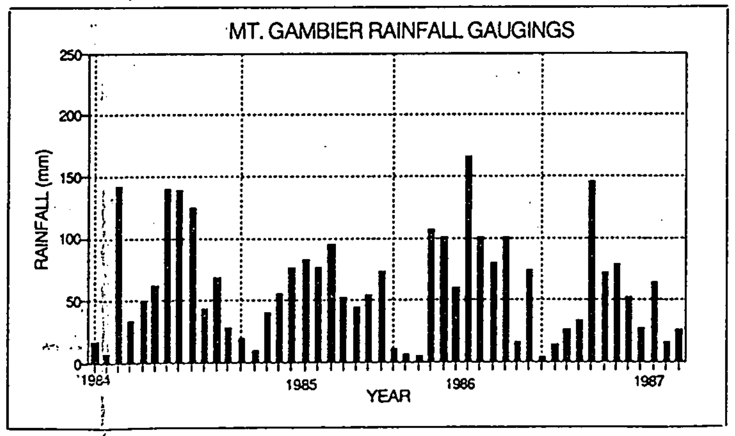


Figure.......13

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED J.V.	C.D.O. 6/4/93 DATE
BLUE LAKE HYDROGEOLOGICAL INVESTIGATION	DRAWN B. Donovan	SCALE As Shown
OBSERVATION WELL WATER LEVELS versus TIME and RAINFALL STATISTICS	DATE Mar. 1993 / CHECKED	PLAN NUMBER 93 - 441

Job No.5724

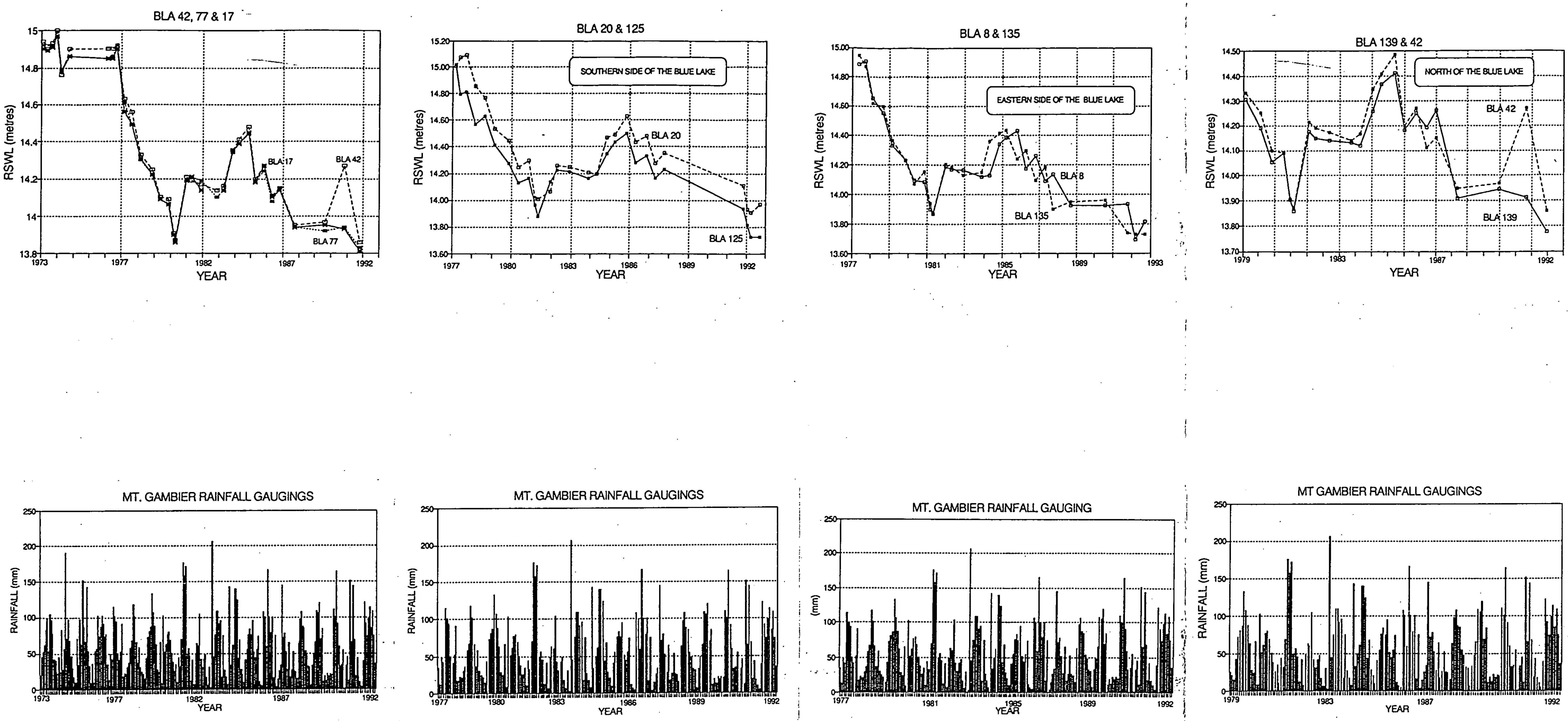


Figure.......14

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA

BLUE LAKE HYDROGEOLOGICAL INVESTIGATION

OBSERVATION WELL WATER LEVELS versus TIME and RAINFALL STATISTICS

COMPILED J.V.	H. Laubach 6/4/93 C.D.O. DATE	
DRAWN B. Donovan	SCALE As Shown	
DATE Mar. 1993	PLAN NUMBER	
CHECKED	93 - 442	

Job No.5724

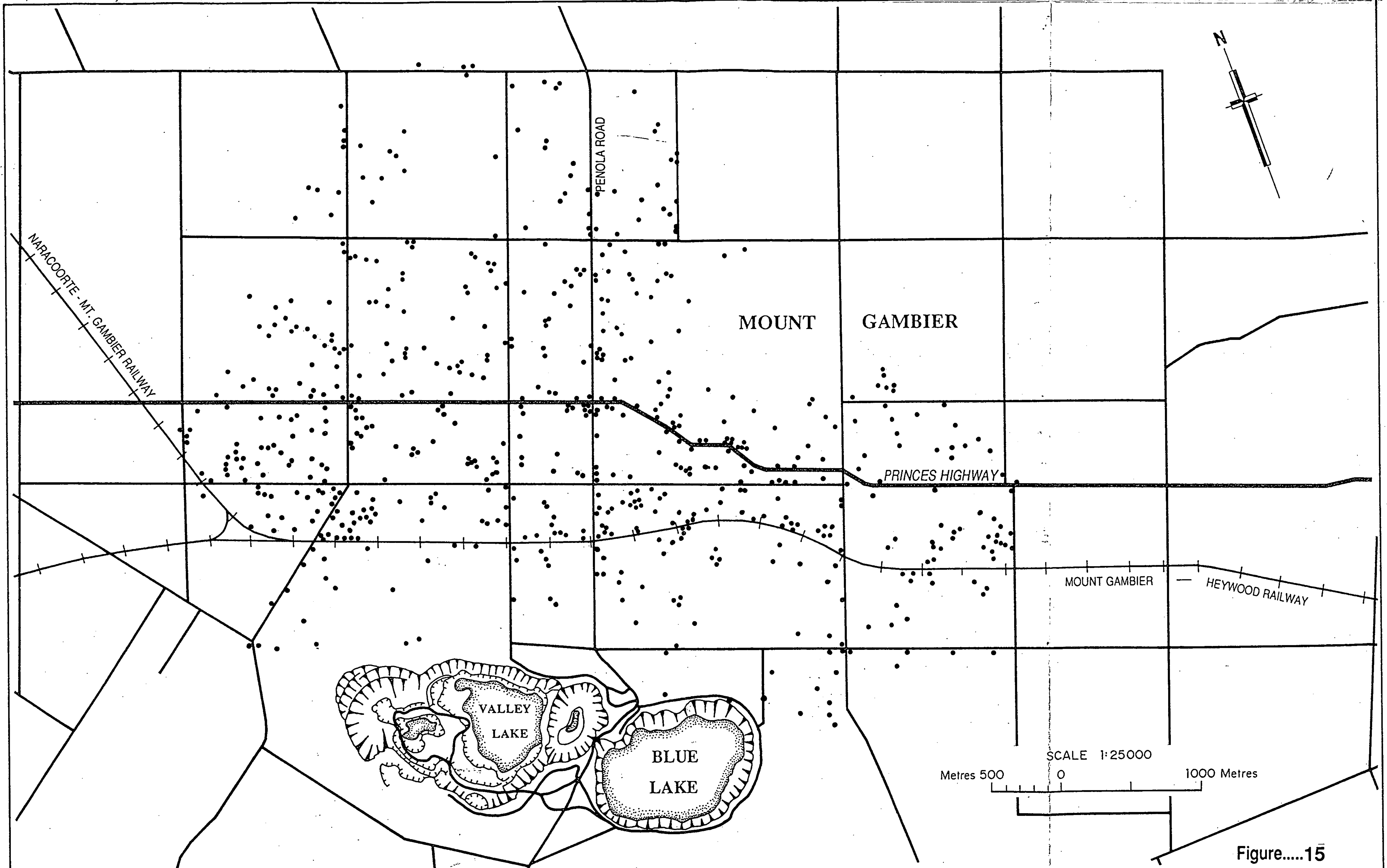


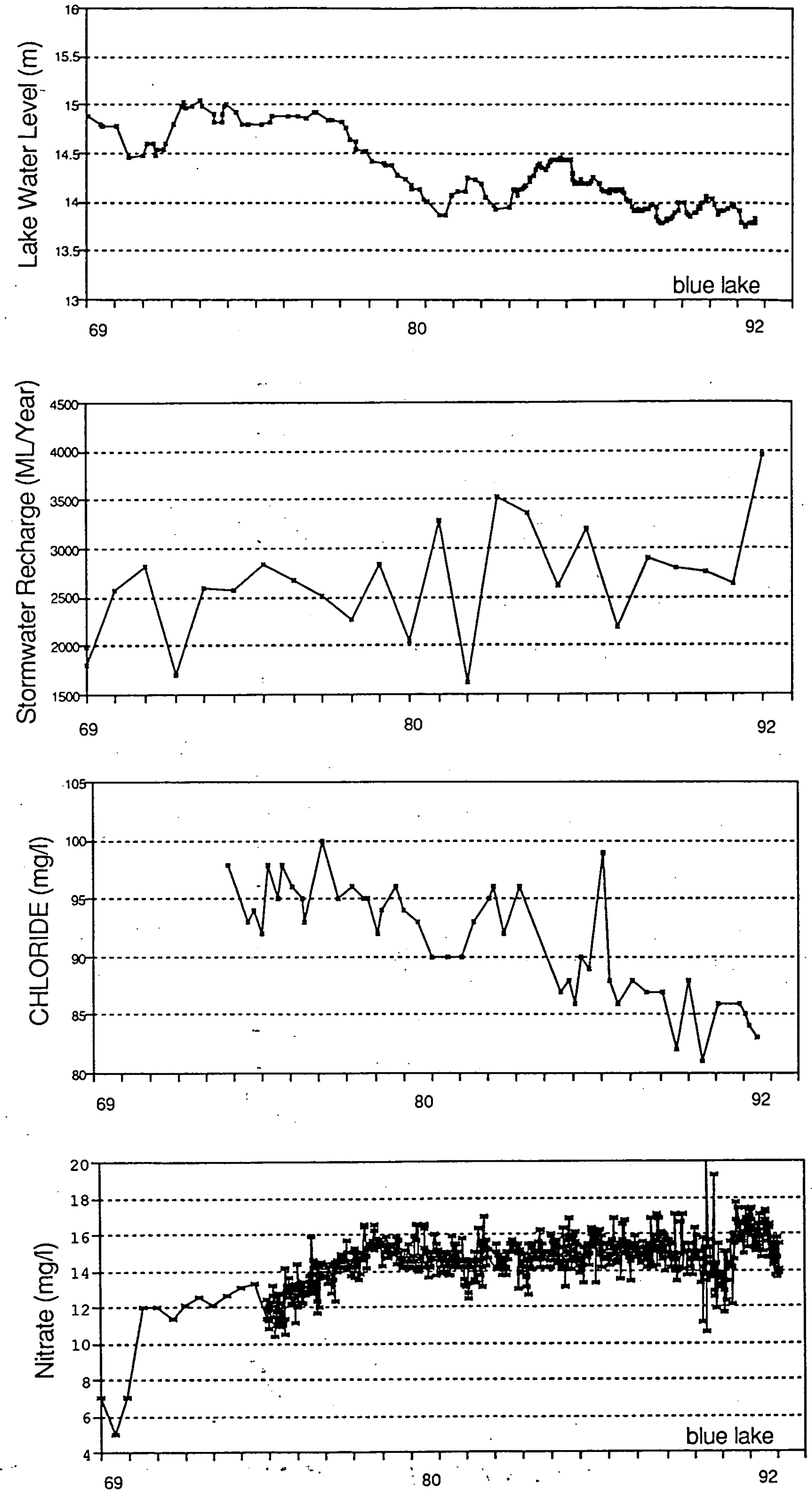
Figure.....15

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

BLUE LAKE HYDROGEOLOGICAL INVESTIGATION

LOCATION OF DRAINAGE WELLS

COMPILED J.V.	C.D.O.	6/4/93 DATE	
DRAWN B. Donovan	SCALE As Shown		
DATE Dec.1992	PLAN NUMBER 93 - 443		
CHECKED			



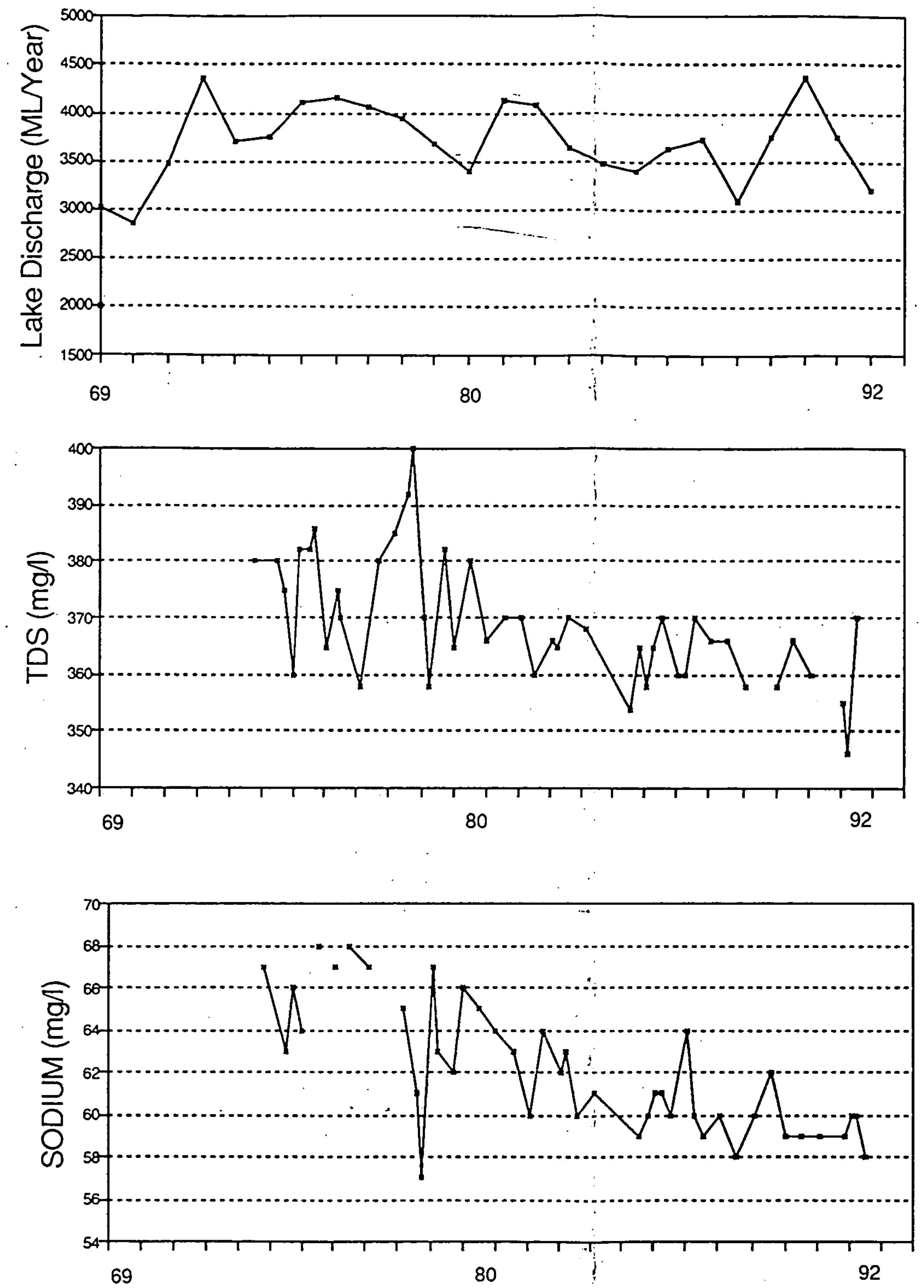


Figure.......16

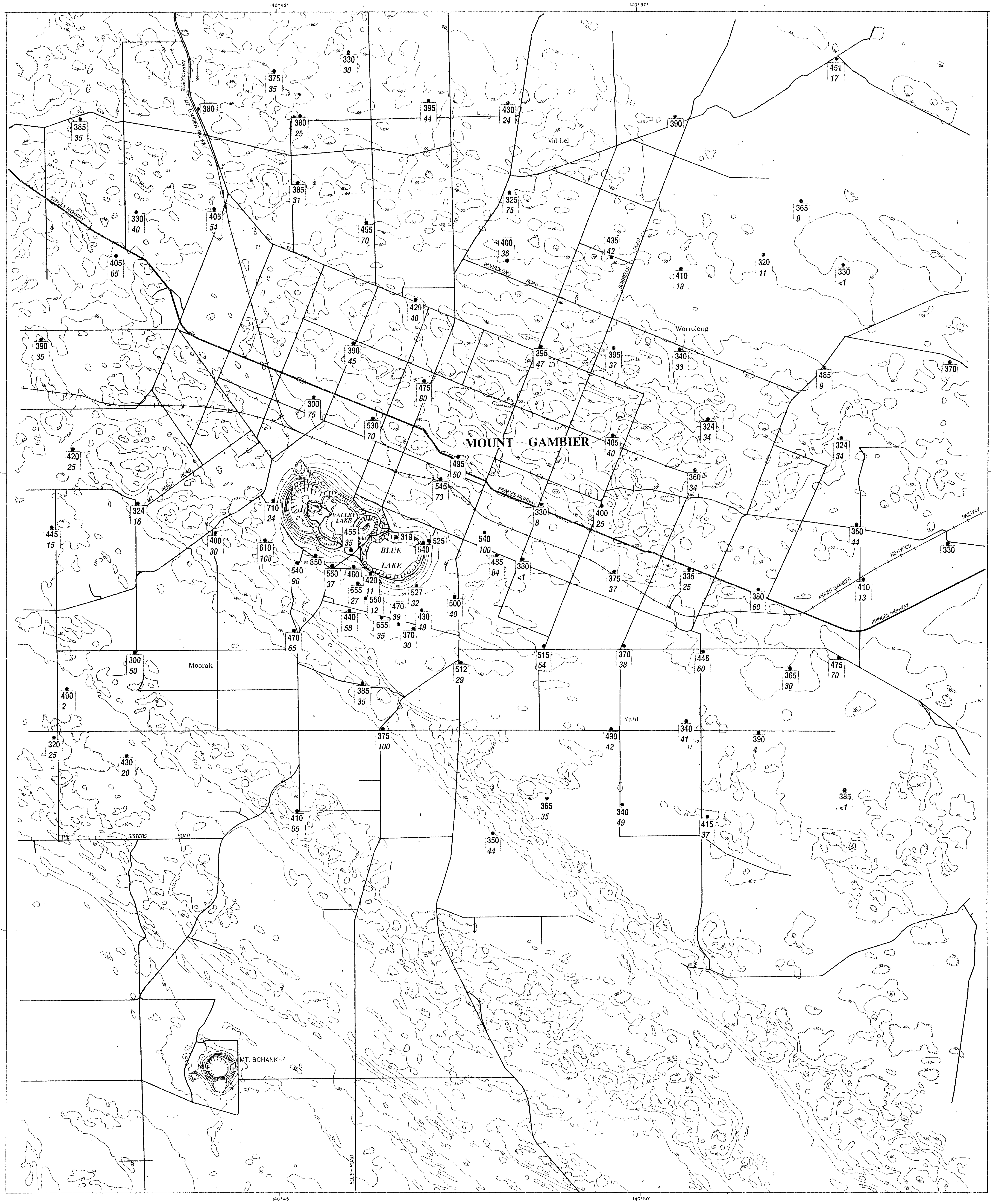
DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

BLUE LAKE HYDROGEOLOGICAL INVESTIGATION

BLUE LAKE TEMPORAL PROFILES

COMPILED J. Lawson	C.D.O.	DATE 6/4/93
DRAWN B. Donovan	SCALE As Shown	
DATE Feb. 1993	PLAN NUMBER	
CHECKED	93 - 444	

Job No.5724



SCALE 1:50 000

METRES 1000 0 1 2 3 4 5 KILOMETRES

LEGEND

●.................Observation Well with
500.................Salinity (mg/L) and
45..................Nitrate value (mg/L)

Figure.....17

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

BLUE LAKE HYDROGEOLOGICAL INVESTIGATION

UNCONFINED AQUIFER
GROUNDWATER SALINITY AND
NITRATE DISTRIBUTION

COMPILED	J. Lawson
DRAWN	B. Donovan
DATE	Dec 1992
CHECKED	
CDG	4/4/93
SCALE	As Shown
PLAN NUMBER	93 - 445

Job No. 5724

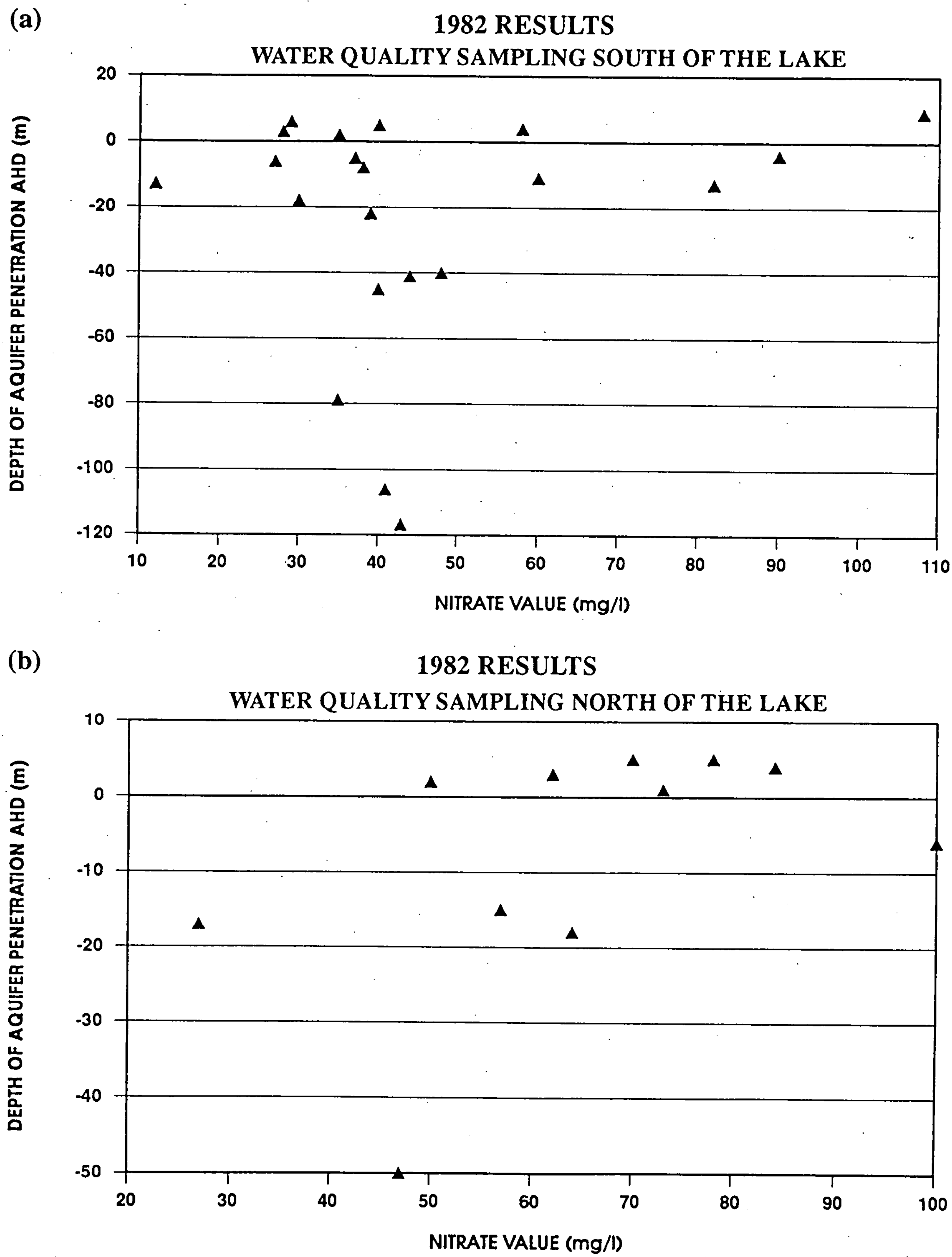


Figure.....18

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

BLUE LAKE HYDROGEOLOGICAL INVESTIGATION

1982 NITRATE VALUES vs AQUIFER PENETRATION
NORTH & SOUTH GRAPHS CLOSE TO BLUE LAKE

DRAWN B. Donovan	COMPILED J. Lawson
DATE 18FEB93	SCALE As Shown
JOB NUMBER 5724	PLAN NUMBER 93 - 446
CDO	

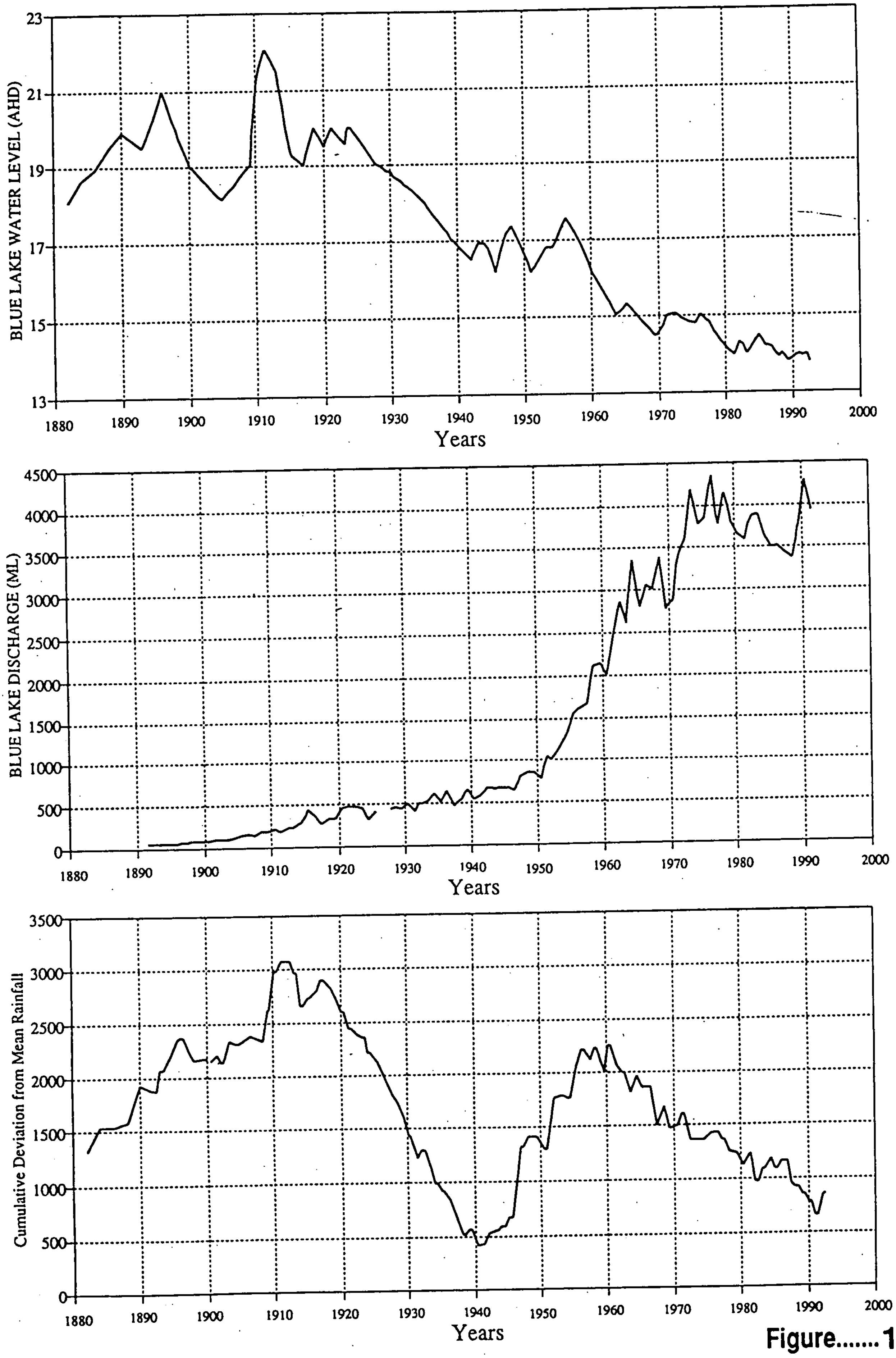
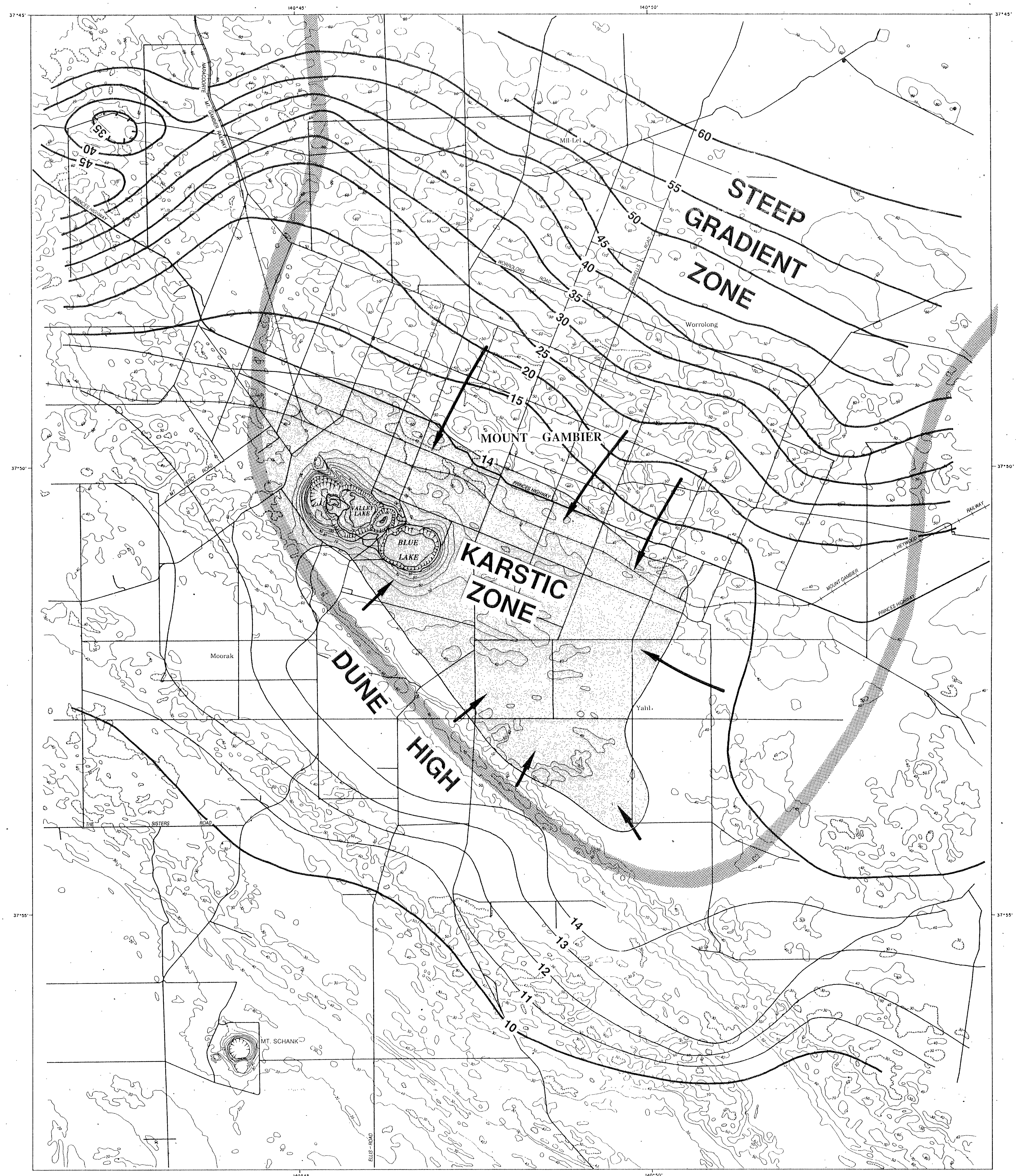


Figure.......19

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED J. Lawson	[signature] C.D.O.	6/4/93 DATE
BLUE LAKE HYDROGEOLOGICAL INVESTIGATION	DRAWN B. Donovan	SCALE As Shown	
WATER LEVELS, DISCHARGE, AND RAINFALL STATISTICS	DATE March 1993	PLAN NUMBER	
	CHECKED	**93 - 447**	

Job No. 5724



SCALE 1:50 000

METRES 1000 0 1 2 3 4 5 KILOMETRES

LEGEND

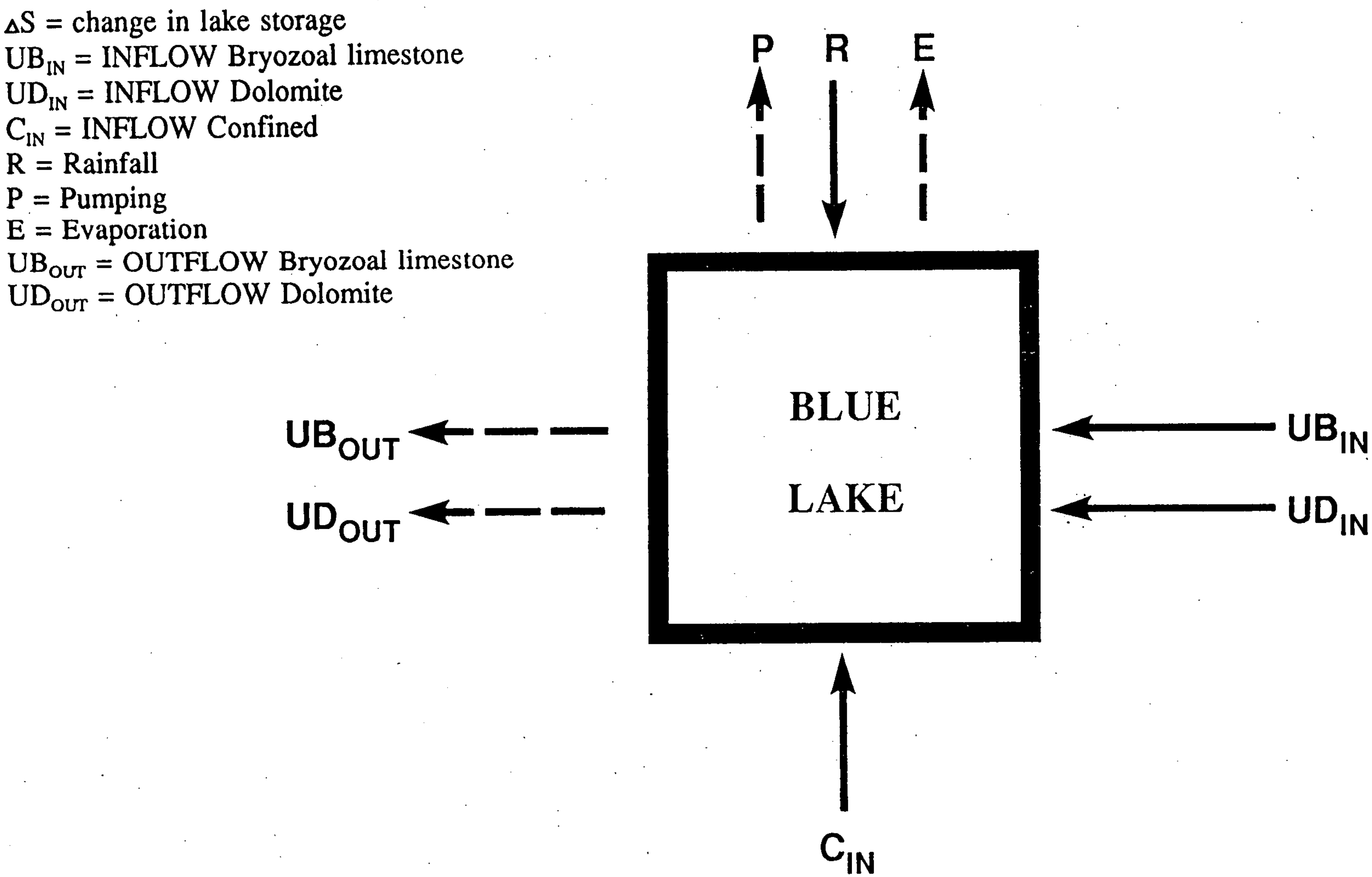
—10— ....Potentiometric contour in metres.(AHD)

Figure.....20

DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA	COMPILED J. Lawson
	DRAWN B. Donovan
BLUE LAKE HYDROGEOLOGICAL INVESTIGATION	DATE March 1993
	CHECKED 6/4/93
POTENTIAL BLUE LAKE GROUNDWATER CAPTURE ZONE	SCALE As Shown
	PLAN NUMBER 93 - 448

Job No. 5724

BLUE LAKE WATER BUDGET



$$\Delta S = UB_{IN} + UD_{IN} + C_{IN} + R - P - E - UB_{OUT} - UD_{OUT}$$

BLUE LAKE SCHEMATIC GEOLOGICAL SECTION

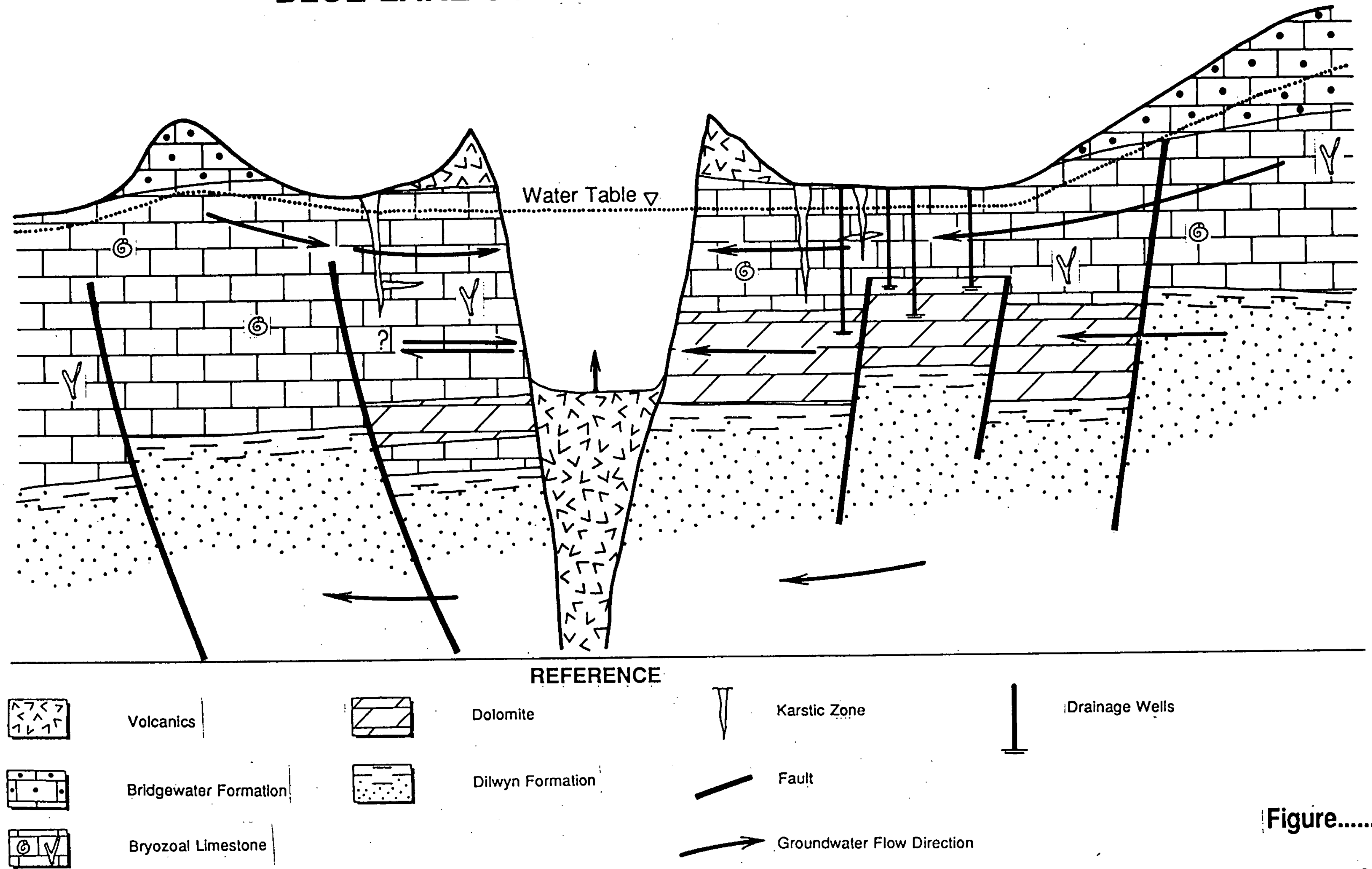


Figure.......22

93 - 450

Job No.5724

SADME