NSW Great Artesian Basin Status Report

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Executive Summary

The NSW Great Artesian Basin Status Report provides an overview of the nature of the Great Artesian Basin (GAB) in NSW, and describes the impact of groundwater extraction on the status of the resource. Although the report can be read as a stand-alone document, it is designed to compliment the NSW GAB Groundwater Management Plan (2000), by providing facts, figures and interpretations on groundwater pressures and flow, quality, allocation and extraction.

The New South Wales portion of the GAB covers over 207,000 km^2, which represents about 20% of the area of New South Wales and about 11% of the total area of the basin. The productive aquifers of the GAB in NSW are mostly less than 600m thick and less than 500m from the surface. In the northern Coonamble Zone and the north west corner of the State, the thickness increases to between 600m and 1200m and the depth from the surface increases to between 500m and 1000m. East of the Goondiwindi monocline, in the North Star-Croppa Creek area, the top of the productive aquifer is less than 100 m from surface, and is typically less than 200 m thick. Groundwater supplies are obtained from the permeable sandstone aquifers, which in places are confined under sufficient pressure to allow groundwater to flow freely to the surface. Groundwater recharge takes place chiefly along the eastern fringe of the GAB, where the sandstone aquifers are exposed to the surface. Groundwater flow is to the north and west in the eastern parts of the NSW GAB, however further west, groundwater flows south across the Queensland border. Natural groundwater discharge from artesian springs takes place in the Bogan River-Carinda and Yantabulla-Bourke-Weilmoringle areas.

At the national level, the Great Artesian Basin Consultative Council (GABCC) has proposed a division of the GAB into management zones on the basis of use, pressure conditions, recharge/discharge characteristics and biogeographical regions. The NSW portion of the GAB has been divided into four zones consistent with the Basin-wide zoning. They are:

Zone 1:	Recharge Zone
Zone 2:	Coonamble Zone
Zone 3:	Warrego Zone
Zone 4:	Central Zone

Although the volume of groundwater stored in the GAB is massive (est. 10,000 million ML, basin-wide), and the annual discharge from free-flowing bores and abstraction from the GAB in NSW is a mere 0.02 % of the estimated storage, this seeming low amount of extraction has had a significant impact upon groundwater pressure and bore flow rates. A steep decrease in pressure and flow occurred during the early stages of development which caused many bores to cease to flow. Pressure loss has occurred across more than 80% of the NSW portion of the basin, and free-flowing conditions exist in less than 50% of the GAB in NSW at present. However, the rate of pressure and flow loss has decreased steadily, and is currently close to zero in many areas of the Basin. Further groundwater pressure loss occurs during the pumping season in areas of recent irrigation development in the northern part of the Recharge Zone.

Groundwater bores in the GAB fall into 2 broad categories:
- stock and domestic, either unlicensed, or, licensed in perpetuity, with or without a volumetric allocation
- "high yield" (irrigation, mining, recreation, town water supply) with a renewable license and volumetric allocation.

The main use of GAB groundwater is stock watering, however other purposes include irrigation, town water supply, tourism (spa), mining and environmental. The groundwater is generally suitable for these purposes, as total salinity is less than 1000 mg/L across the large areas of the basin. However, groundwater is generally unsuitable for irrigation, apart from the recharge areas, owing to elevated sodium levels.

Natural artesian springs in the GAB are important Groundwater Dependent Ecosystems (GDEs), which owe their existence solely to the presence of discharging GAB groundwater. There are approximately 45 sets of artesian springs associated with the GAB in NSW, however due to declining pressures only 30 continue to have permanent seeps. Other GDE issues include the alteration of the arid rangeland ecosystem through the introduction of grazing activities and the presence of permanent water brought about by the bore drain network.

Most of the water currently extracted from the GAB is wasted by deteriorated or uncontrolled bores and a network of outmoded, wasteful bore drains. The control of this water through capping and piping is essential to any successful management outcome in the GAB. The aim over the next 5 years is to cap and pipe 60 targeted bores, which will restoring artesian pressure to acceptable levels and replace more than 2000 kilometres of bore drains. This will reduce wastage by 15,000 megalitres annually.

Groundwater pressure and bore flow monitoring is currently conducted by a single team out of Moree. Current monitoring arrangements are insufficient to meet the demands for groundwater management, hence are due for a review.

A greater understanding of the recharge processes and groundwater flow characteristics is the key research requirement for the GAB. Recharge must be reliably estimated or measured in order to manage the GAB groundwater system in a sustainable manner. Recharge research has particular sub-regional importance to the areas affected by intensive groundwater extraction in the Border Rivers/Intake Bed region (northern part of Zone 1).

Additional research developments include a Basin-wide numerical model and a study of the hydrochemistry of GAB groundwater undertaken by the Bureau of Rural Sciences.

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1 Introduction

The Great Artesian Basin (GAB) is one of the largest artesian basins in the world. The New South Wales portion of the GAB covers over 207,000 km^2, which represents about 20% of the area of New South Wales and about 11% of the total area of the basin.

The objectives of the NSW Great Artesian Basin Status Report is to provide an overview of the nature of the GAB in NSW, and to describe the effect of groundwater extraction on the status of the resource. Although this report can be read as a stand-alone document, it is designed to compliment the NSW GAB Groundwater Management Plan, by providing facts and figures on groundwater pressures and flow, quality, allocation and extraction. The reader who wishes to find more detail on technical aspects is referred to the Great Artesian Basin Resource Study of 1998, commissioned by the Great Artesian Basin Consultative Council (GABCC).

The report is structured into four main parts. Firstly, the hydrogeology and the division of the NSW portion of the GAB into Hydrologic Management Zones is introduced. Then the status of the groundwater resource, in terms of groundwater pressure and flow, water quality and groundwater dependant ecosystems, is outlined. This is followed by a description of current groundwater allocation and licensing, and presentation of information on the current level of groundwater extraction. As the key project targeting pressure restoration in the Basin, basic information on the Cap & Pipe the Bores Program has been provided. Finally, current monitoring arrangements and research are described.

2 Hydrogeology and the Hydrologic Management Zones

2.1 Hydrogeology

Before discussing the division of the NSW portion of the GAB into zones, a brief description of the hydrogeology of the basin is provided. This description is brief; for a more comprehensive treatment of the geology of the GAB refer to the GABCC Resource Study (1998). The groundwater resources of the GAB are described in more detail in Chapter 3.

The GAB in NSW is part of two sub-units of the larger Basin - these are the Surat Basin and the Eromanga Basin (see Fig. 9, GABCC Resource Study, 1998). The Surat Basin underlies north eastern NSW, where it extends southward from Queensland as the Coonamble Embayment. The Eromanga Basin underlies the western half of the state, separated from the Surat Basin by the Nebine Ridge.

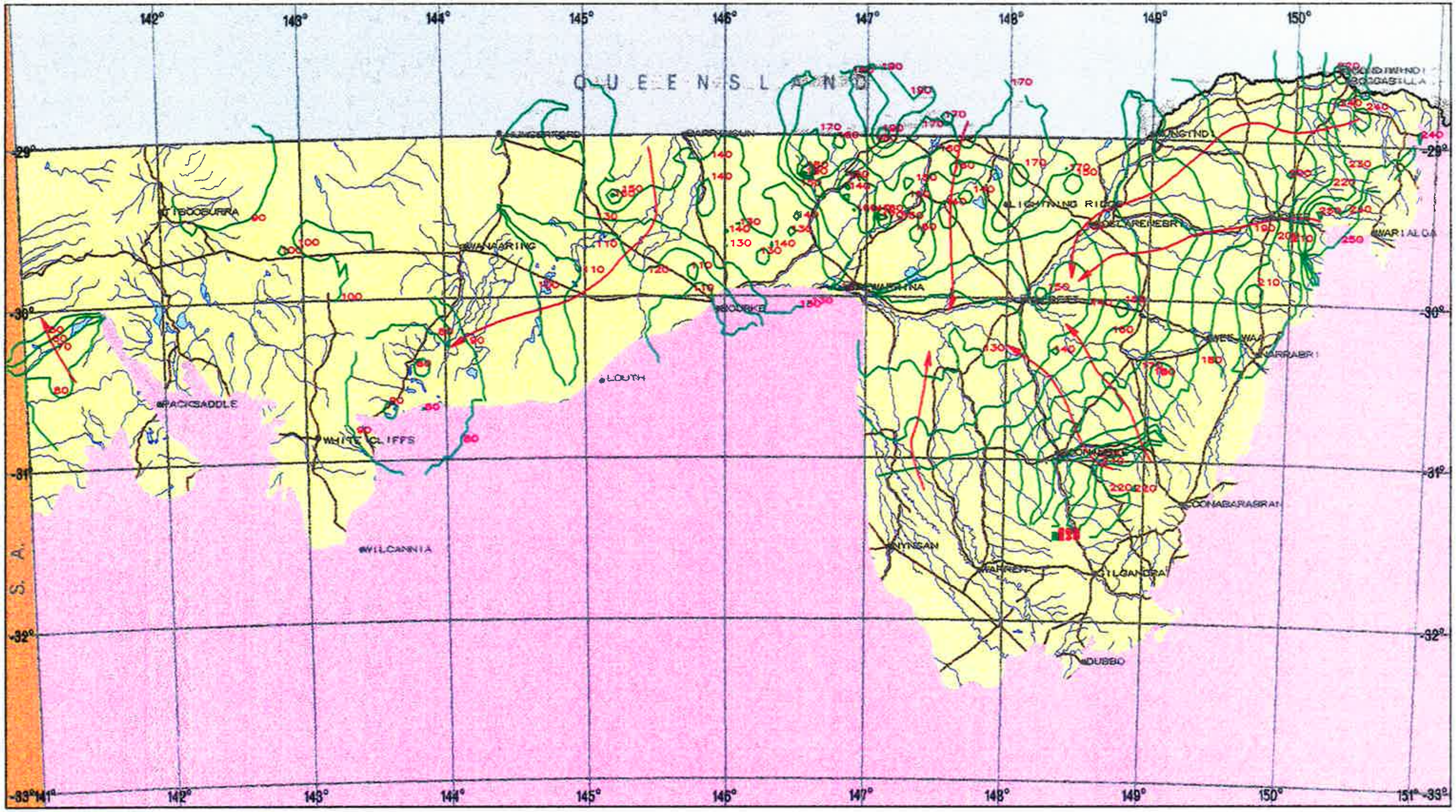
The GAB sedimentary sequences consist of alternating layers of porous and permeable sandstones and low permeability shales, siltstones and mudstones. The aquifers in NSW are mostly less than 600m thick and less than 500m from the surface. In the Lightning Ridge-Moree area and the north west corner of the State, the thickness increases to between 600m and 1200m and the depth from the surface increases to between 500m and 1000m. East of the Goondiwindi monocline, in the North Star-Croppa Creek area, the top of the sandstones are less than 100 m from surface, and are typically less than 200 m thick

Groundwater supplies are obtained from the permeable sandstone aquifers, which in places are confined under sufficient pressure to allow groundwater to flow freely to the surface. Groundwater recharge takes place mainly along the eastern fringe of the GAB, where the sandstone aquifers are exposed at the surface.

Figure 1 shows groundwater pressures, or potentiometric contours, across the NSW portion of the GAB. Groundwater flows from areas of high pressure to areas of low pressure, perpendicular to the pressure contours. The diagram shows that movement is generally toward the west, however groundwater recharging in the south flows toward the north west, where it meets the westerly flowing groundwater. The pattern of groundwater movement is complex between Brewarrina and Barringun, whilst the scarcity of data in the far west makes flow interpretation difficult. Groundwater flows from Queensland into NSW, apart from an area east of Goondiwindi, which shows groundwater flow into Queensland.

Natural groundwater discharge from artesian springs takes place in the Bogan River-Carinda and Yantabulla-Bourke-Weilmoringle areas. Free-flowing conditions at present occur in less than 50% of the GAB in NSW (refer Chapter 3).

Table 1 is a summary of the estimated hydraulic characteristic of the whole GAB aquifer system, with NSW shown alone where data is available.



GREAT ARTESIAN BASIN (NSW)

POTENTIOMETRIC SURFACE DATA
POST 1986 (m AHD)

SCALE
50 0 50 100 150

Produced by
Surface and Groundwater Processes Unit,
Centre for Natural Resources, 2000.

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LEGEND

- Potentiometric Head (m AHD)
- Groundwater Flowline

Figure 1

Table 1: Bulk Hydraulic Parameters of the GAB Aquifer System

Basin Parameter	Whole GAB	NSW
Area (km^2)	1.81 million	207,000
Maximum Thickness (m)	3,000	1,200
Volume of Water in Storage (ML)	10,000 million	
Recharge Area	10 % of Basin area	32,400 km^2
Rainfall Recharge (ML/year)	1 million	195,000
Inflow from Queensland (ML/year)		95,000 ML/year
Outflow to Qld & SA (ML/year)		3,000
Upward leakage (ML/year)		152,000 (approx)
Number of mound springs	11 main groups	45 sets, 30 still active
Discharge to mound springs (ML/year)		1000 (approx.)
Transmissivity (m^2/day)	10 - 20,000	
Hydraulic Conductivity (m/day)	10^{-1} - 10^{-4}	
Porosity	10 - 30 %	
Average Storage Coefficient	1 x 10^{-5}	
Potentiometric surface gradients	1:2,000 (approx.)	
Average groundwater velocities (m/year)	1 – 5	1 - 5
Maximum Pressure (kPa)	1,300	
Temperature of water (^{0}C)	Ave. 30-50, max. 100	Max. 76
Age of waters (years)	up to 1 million	
Max. depth to the top of the main aquifer (m)		1000 m

2.2 The Hydrologic Management Zones

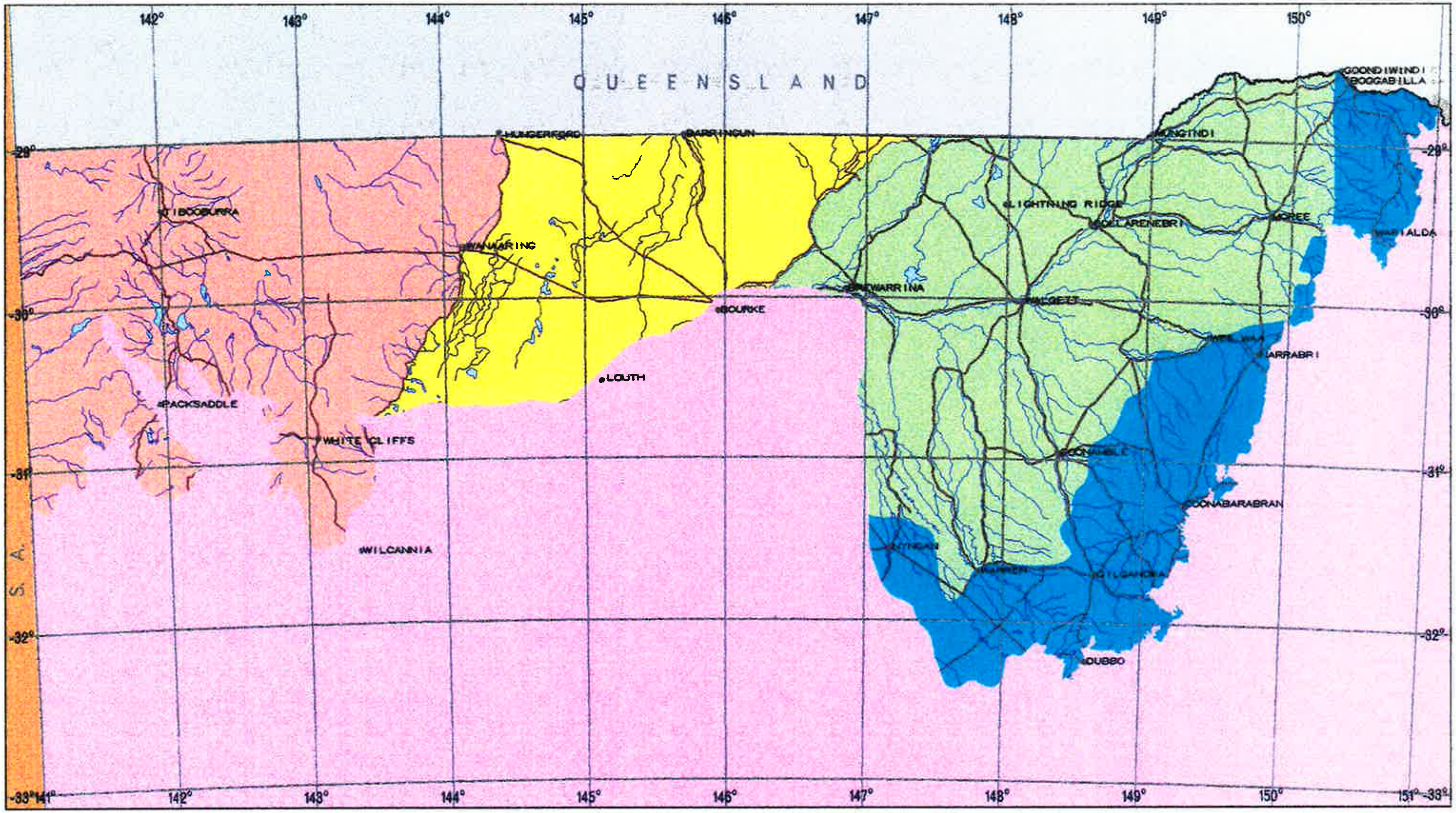
Identification of individual management zones, each with its own management goals and rules, is part of a key national strategy for the development of best management practice for the productive use of GAB water. At the national level, the GABCC has proposed a division of the GAB into management zones on the basis of use and pressure conditions, recharge/discharge characteristics and biogeographical regions (GABCC Resource Study, 1998, p137). Under the Great Artesian Basin Sustainability Initiative, the Commonwealth Government will distribute funds for cap and pipe works on the basis of management zones. This chapter defines the zoning of the NSW portion of the GAB, which are consistent with the zoning proposed Basin-wide, but with minor refinements to meet State requirements.

The proposed division of the NSW portion of the GAB into hydrologic management zones is shown in **Figure 2**. Each zone is described in the following section.

2.2.1 Zone 1: Recharge Zone

Groundwater recharge takes place chiefly along the south eastern fringe of the GAB, in an area known as the "Intake Beds". Groundwater enters the main Pilliga Sandstone aquifer directly through exposed outcrop, or via overlying strata where there is potential for downward groundwater movement. This area defines Zone 1, the Recharge Zone (**Figure 2**).

The northern-most part of the Recharge Zone is bordered by the Goondiwindi Monocline to the west, the Queensland border to the north, and the eastern extent of the Basin to the south and east (**Figure 2**). The main aquifer, the Pilliga Sandstone, outcrops as undulating hills in the eastern



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GREAT ARTESIAN BASIN (NSW)

GAB HYDROLOGIC ZONES (NSW)

SCALE
50 0 50 100 150
kilometres

LEGEND

- 🟦 Zone 1: Recharge
- 🟩 Zone 2: Coonamble
- 🟨 Zone 3: Warrego
- 🟥 Zone 4: Central

Figure 2

half of the Zone. In the area between the Goondiwindi Monocline and the outcrop, the Pilliga Sandstone is relatively shallow; between 100 and 300 metres below surface. The area is characterised by groundwater with generally lower Sodium Absorption Ratios (SAR) than other areas, and hence has been developed for high volume irrigation extraction. Free-flowing conditions are absent apart from the far north western part of the Zone. The area contains no mound springs.

Further south, the outcrop of the Pilliga Sandstone narrows markedly coincident with the location of the Gwydir River, and where the Goondiwindi Fault is no longer present. At Narrabri, the western edge of the zone extends further into the basin. The western boundary of the zone is defined by a change in the direction of vertical groundwater flow. Within Zone 1, the potential for groundwater flow is downward, from the overlying aquifers into the main Pilliga Sandstone aquifer. West of the boundary, the groundwater flow potential is upward.

2.2.2 Zone 2: Coonamble Zone

Groundwater hydrology within the Coonamble Zone is governed by recharge occurring in the eastern recharge zones, driving flow toward the north and west. This flow meets south west flowing groundwater from Queensland in the north west of the Coonamble Zone. A hydraulic constriction caused by basin structure, combined with the convergence of these flows, has resulted in the development of mound springs in the Bogan River-Carinda area. The zone is characterised by a high density of bores, particularly in the southern part, and high flowing bores with numerous bore drains in the north. Free-flowing conditions exist over most of the zone.

2.2.3 Zone 3: Warrego Zone

The boundary between the Coonamble and Warrego Zones is formed by the Culgoa River. Whereas the Coonamble Zone hydrology is driven by groundwater recharge in the east, groundwater flow across the Queensland border from the north drives the groundwater dynamics in the Warrego Zone. The south and north flowing groundwater converge and are channelled west, governed by the flow regime and basin structure.

Clusters of high bore density occur in a wide area north of Bourke, extending to and across the Queensland border, and in an area south west of Bourke toward the southern edge of the GAB. The Yantabulla-Bourke-Weilmoringle mound springs occur in the areas of high bore density.

2.2.4 Zone 4: Central Zone

The Central Zone is divided from the Warrego Zone by the Hungerford-Wanaaring-White Cliffs Road. The boundary follows a S-SW direction, roughly parallel with the direction of groundwater flow. In relation to the other areas of the NSW portion of the GAB, bore density is low, and free-flowing conditions are absent across a majority of the area. Hence groundwater utilisation is relatively limited, with very few bore drains.

3 Status of the Groundwater Resource

3.1 Groundwater Pressure and Flow

3.1.1 Pressure Losses

The volume of groundwater stored in the GAB is massive (est. 10,000 million ML). Assuming NSW holds 10% of the water, 1,000 million ML of groundwater is stored in the NSW portion of the GAB. The annual extraction and free-flowing discharge from the GAB in NSW is a mere 0.02 % of the estimated storage. However, this seeming low amount of extraction has had a significant impact upon groundwater heads (expressed in metres, and frequently described as pressures or water levels), which in turn has impacted upon the flow rate of free-flowing bores.

In many instances, the free flowing nature of the GAB is as important as the water itself. An alarming decrease in the pressure, and hence flow rate, were witness in the early stages of development. This caused some bores to cease to flow. A number of graphs and maps have been produced to illustrate these effects.

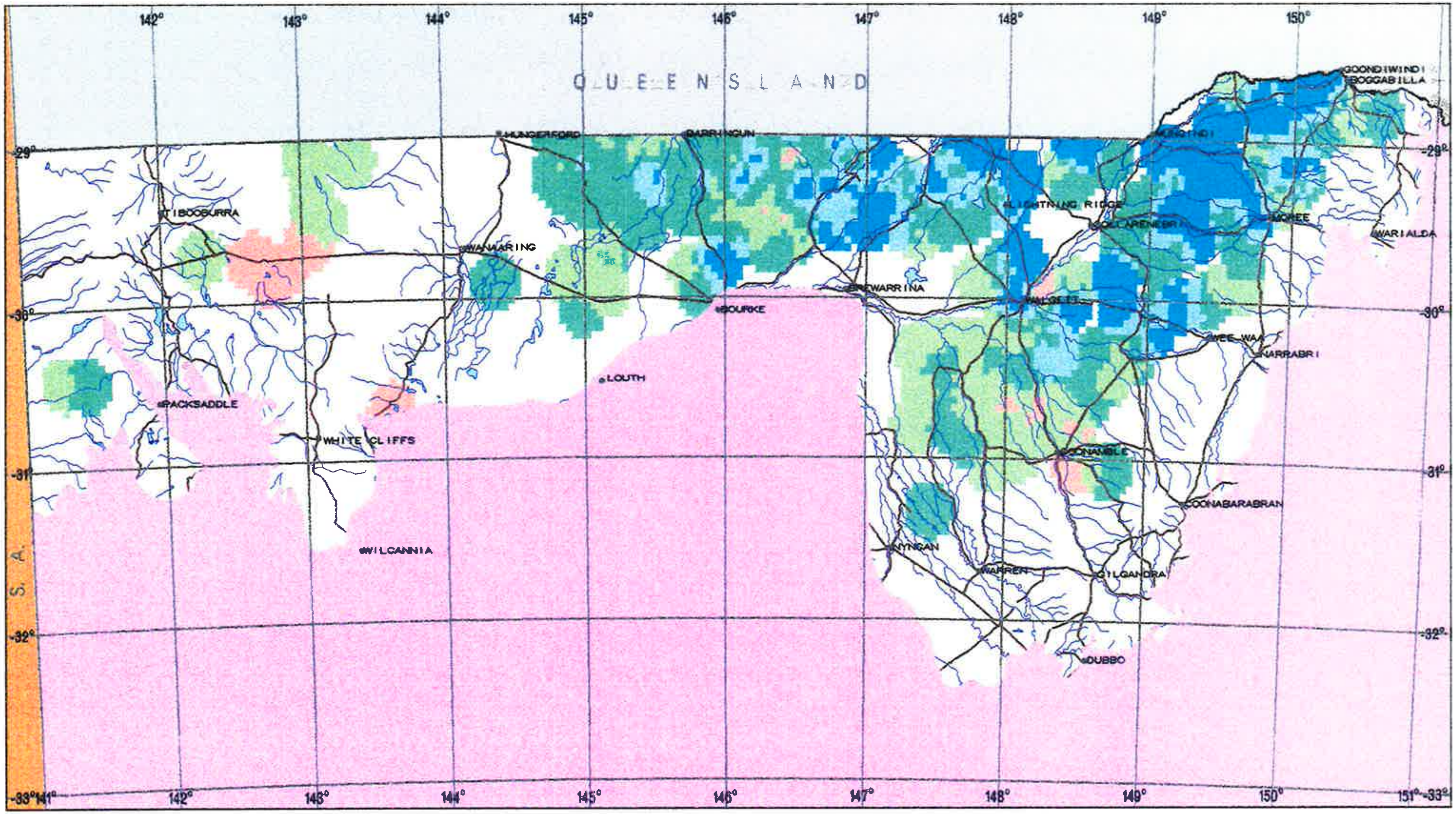
Figure 3 shows the difference in pressure heads, in metres, across the NSW portion of the GAB. This is an area representation based on individual bore data. A pressure difference for each bore was determined by subtracting the last pressure measurement post 1980 from the first measurement prior to 1980. Details of map construction are provided in **Appendix A**.

More than 80% of the NSW portion of the basin has seen pressure losses. Clearly the area suffering the most significant impact is the northern part of the Coonamble Zone. Pressure falls are universal, apart from a number of bores around Coonamble, and the Central Zone. The area north east of White Cliffs is a distortion of the contouring, based on the measurements of a single bore.

3.1.2 Loss of Flow

Falling groundwater pressure results in lower bore flow rates. The most obvious effect of pressure loss is when pressure falls below ground level, causing the bore to cease to flow. The area of non-flowing conditions has been encroaching from the edge of the basin since extraction began. A reduction of the area of free-flowing bores is shown in **Figure 4**, between 1920 and 1954, and from 1954 to 1995. A well-defined line separates areas of flowing and non-flowing condition in the Coonamble Zone and the Central Zone, however a confusing picture emerges in the Warrego Zone.

Although the area of free-flowing bores continues to decrease, it is decreasing at a diminishing rate. From 1920 to 1954, approximately 70,000 ha/year were lost, whilst from 1954 to 1995, the rate of loss was 47,000 ha/yr. It is difficult to construct flow/no flow maps over a series of years, but a better appreciation of the rate of pressure declines over time can be gained from hydrographs (**refer Section 3.1.3**).



GREAT ARTESIAN BASIN (NSW)

HEAD DIFFERENCES (PRE 1980 & POST 1980)

DATA POINTS CONTOURED

SCALE

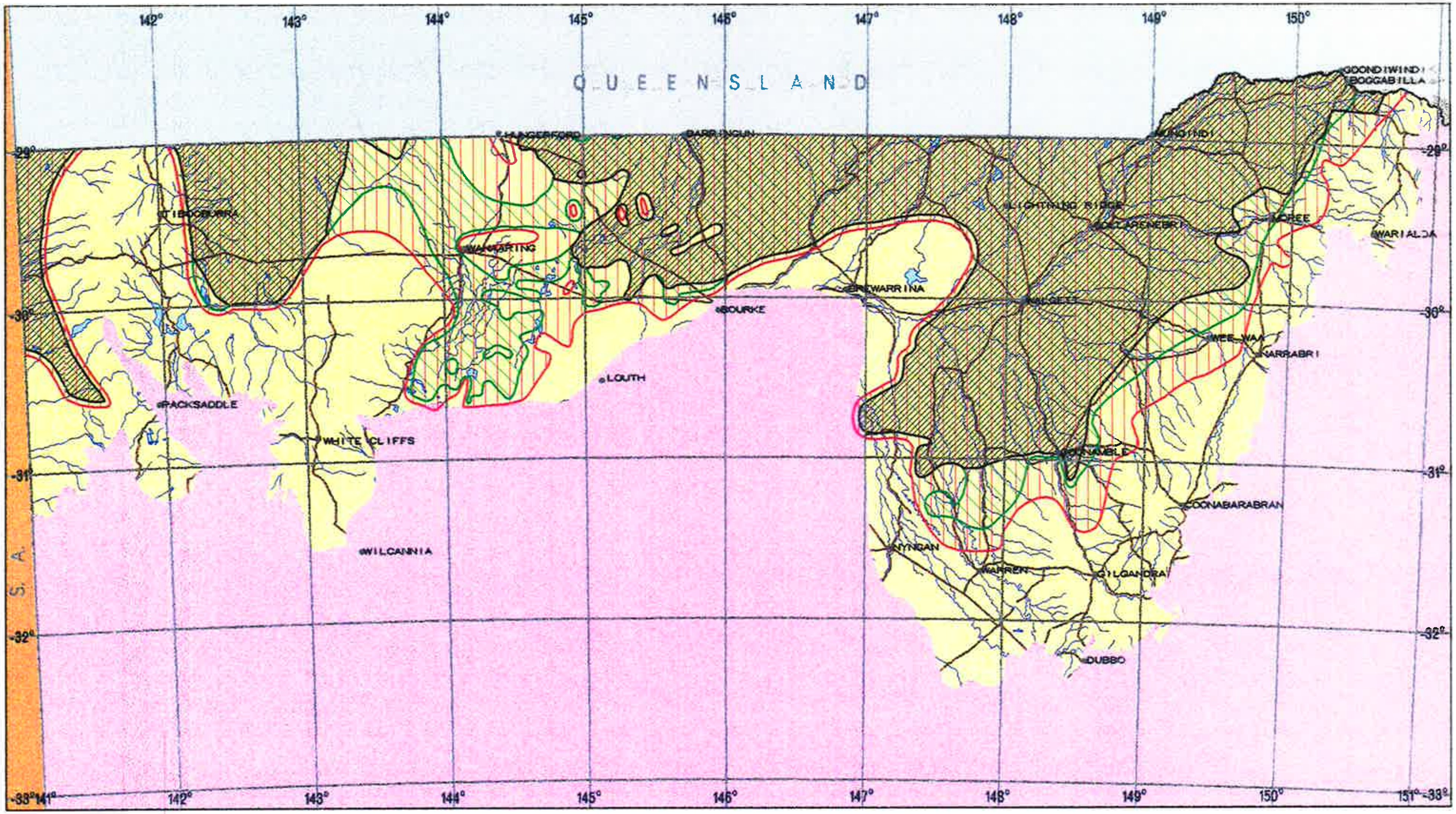
50 0 50 100 150

LEGEND

- 🟥 Rise
- 🟩 Fall 0-4 m
- 🟩 Fall 4-12 m
- 🟦 Fall 12-27 m
- 🟦 Fall >27 m
- ☐ No data

Figure 3

Produced by
Surface and Groundwater Processes Unit,
Centre for Natural Resources, 2000.



Produced by
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Centre for Natural Resources, 2000.

GREAT ARTESIAN BASIN (NSW)

AREAS OF FLOWING BORES

SCALE
50 0 50 100 150
kilometres

LEGEND
🟥 Flow 1920
🟩 Flow 1954
▨ Flow 1995

Figure 4

The current status of flowing bores is shown in two maps. **Figure 5** shows all bores that continue to flow as red dots. Green bores have either never flowed or have ceased to flow. The intermingling of red and green dots in the Warrego Zone demonstrates that no clear line separates areas of free or non flowing conditions in that area.

Latest bore flow rates are shown in **Figure 6**. This is contoured representation based on individual bore data. Highest flows occur in the north eastern Coonamble Zone and the eastern Warrego Zones, and in areas of the Central Zone. An over interpretation by the contouring software has shown areas of flowing bores which are clearly outside the flow/no-flow boundary defined in **Figure 4**.

3.1.3 Hydrographs

Site specific pressure changes are illustrated by hydrographs, a plot of pressure recorded at a bore over time. Selected key hydrographs which show a variety of pressure behaviour typical across the basin are described below. In addition to the hydrograph shown below, a larger selection of hydrographs is provided in **Appendix B**. The location of all bores is shown in **Figure 7**.

The most common feature of bores with a long record is the significant early loss of pressure, followed by a gradual reduction in the rate of loss. Many bores show this behaviour; bores GW004040 (Brewon No 2, **Figure 8,** *note minus sign indicates head above ground level*) and GW004280 (Kensington, **Figure 9**) are highlighted as classic examples. Both experienced large pressure loss during the first half of the century, but have been steady since the 1960s, and the current rate of loss has declined to zero in both bores. These hydrographs demonstrate that in many areas of the Basin, groundwater pressures are approaching a state of equilibrium.

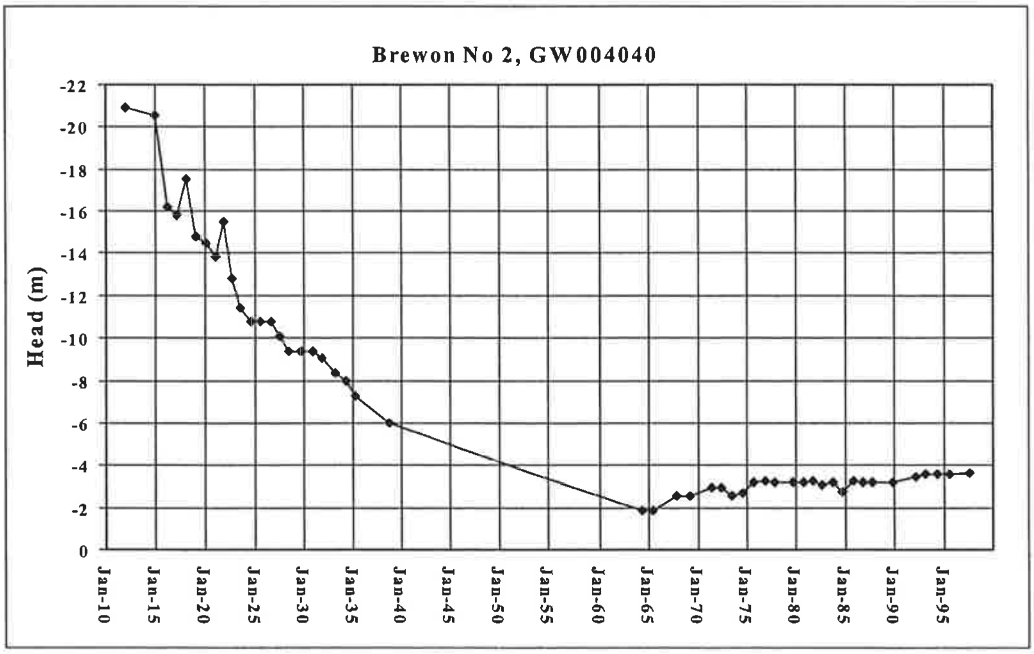
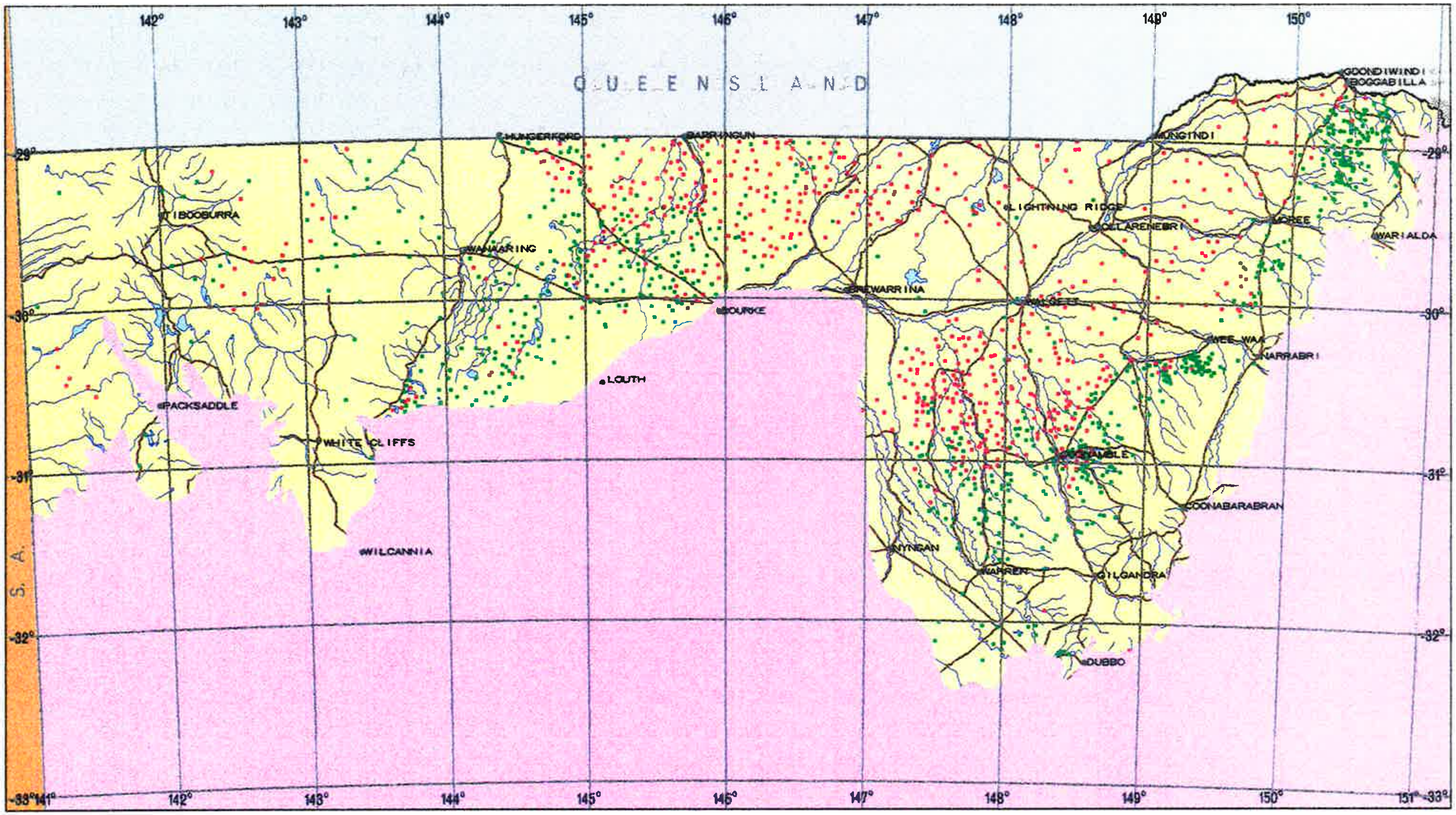


Figure 8: Hydrograph of Brewon No. 2, GW004040



GREAT ARTESIAN BASIN (NSW)

BORE STATUS (1999)

SCALE

50 0 50 100 150

kilometres

LEGEND

- ● Non flowing
- ● Flowing

Figure 5

Produced by
Surface and Groundwater Processes Unit,
Centre for Natural Resources, 2000.

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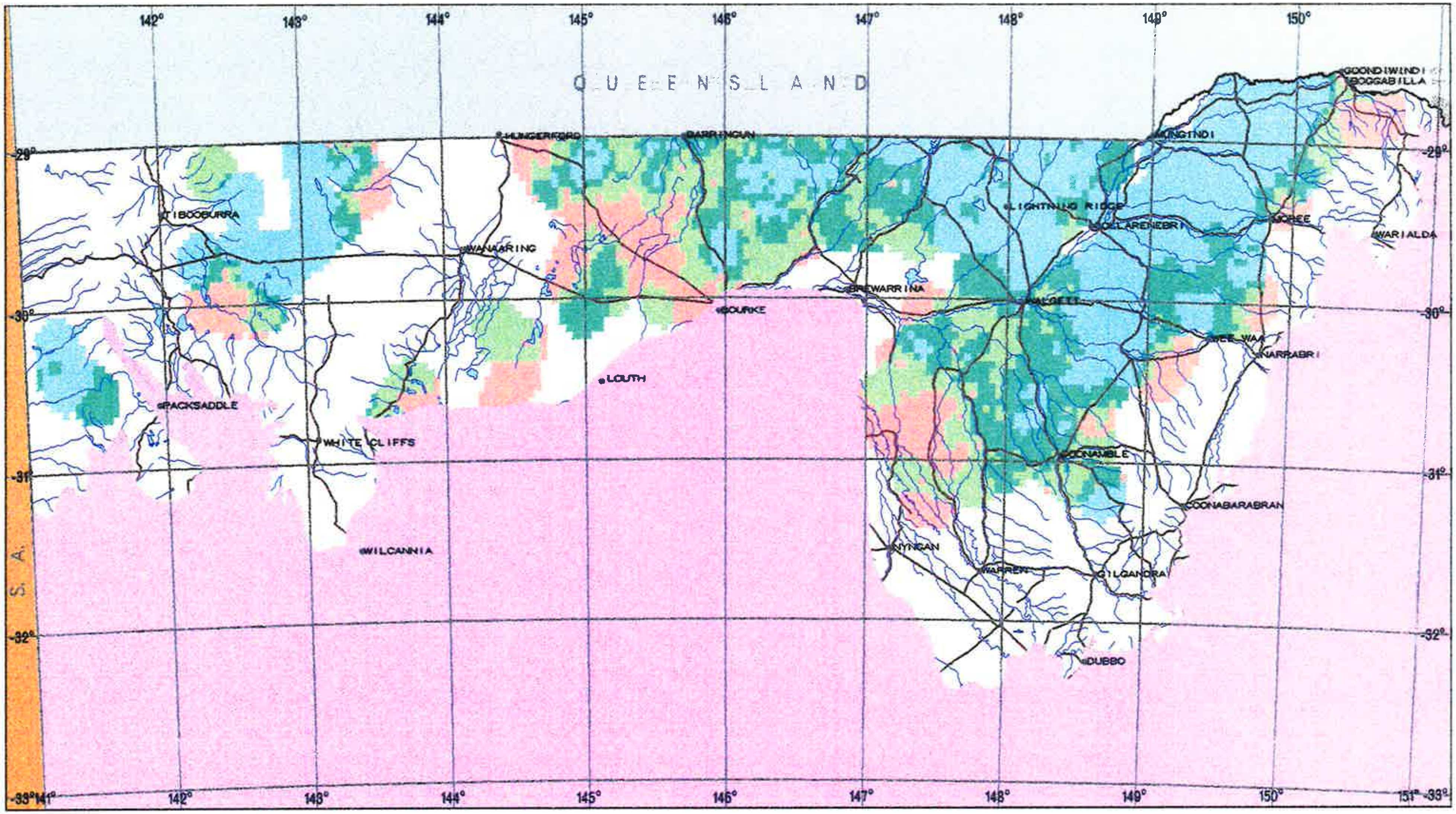


GREAT ARTESIAN BASIN (NSW)

POST 1986 LATEST FLOW

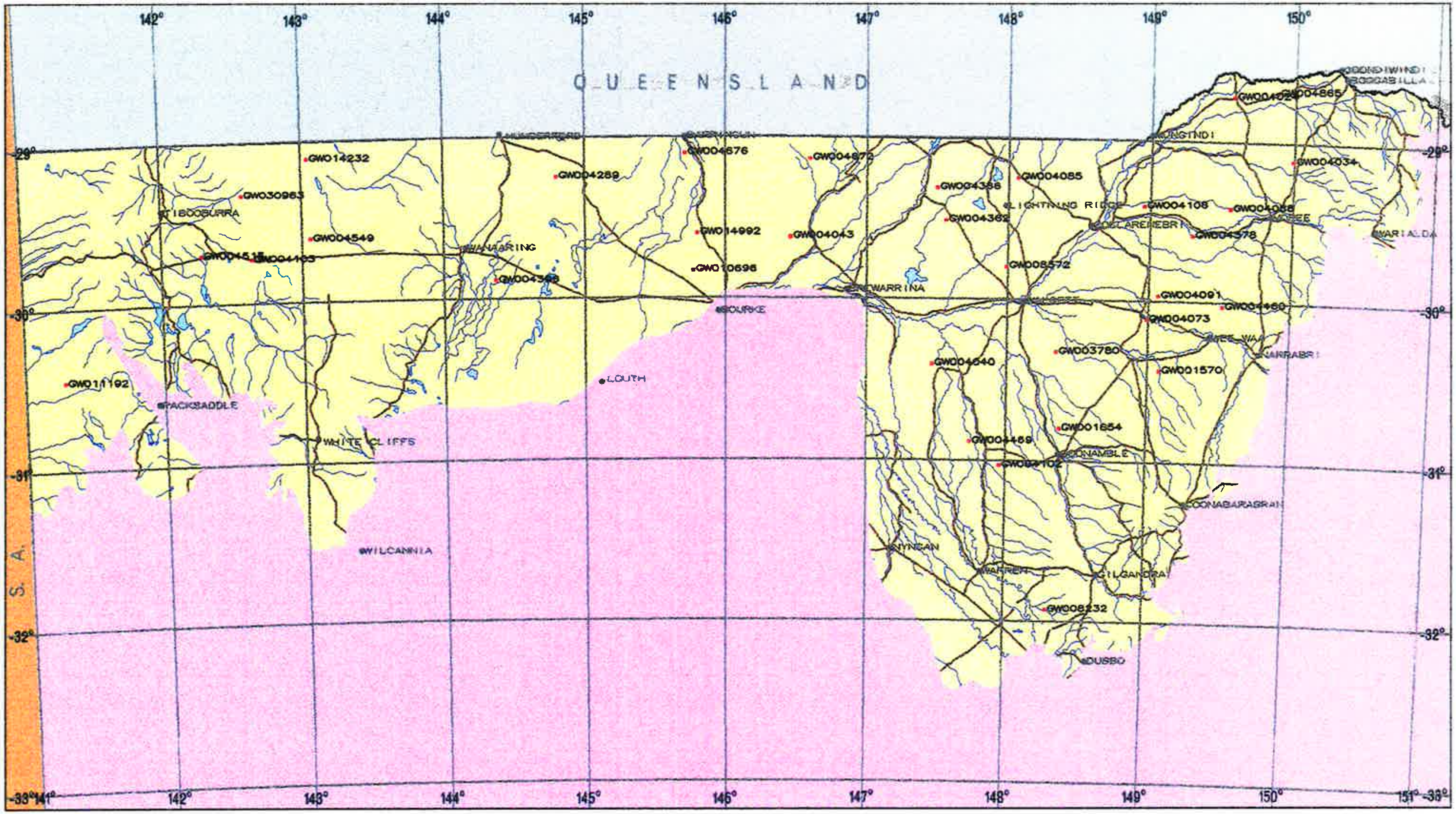
DATA POINTS CONTOURED

LEGEND

- 🟥 <1 L/s
- 🟩 1 - 3 L/s
- 🟩 3 - 7 L/s
- 🟦 >7 L/s
- ☐ No data

Figure 6

Produced by
Surface and Groundwater Processes Unit,
Centre for Natural Resources, 2000.



GREAT ARTESIAN BASIN (NSW)

HYDROGRAPH LOCATIONS

SCALE
50 0 50 100 150
kilometres

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Produced by
Surface and Groundwater Processes Unit,
Centre for Natural Resources, 2000.

Figure 7

However, water pressures are still declining steadily in some areas. Bore GW004685 (Boronga No 2, **Figure 10**) continues to fall at rate today similar to the 1960's. High yield irrigation extraction in the northern part of the Recharge Zone has caused some sudden water pressure losses. Several bores show behaviour similar to GW017247 (Billabong, **Figure 11**), with minor pressure reductions followed by steep, season pressure declines with the onset of irrigation extraction.

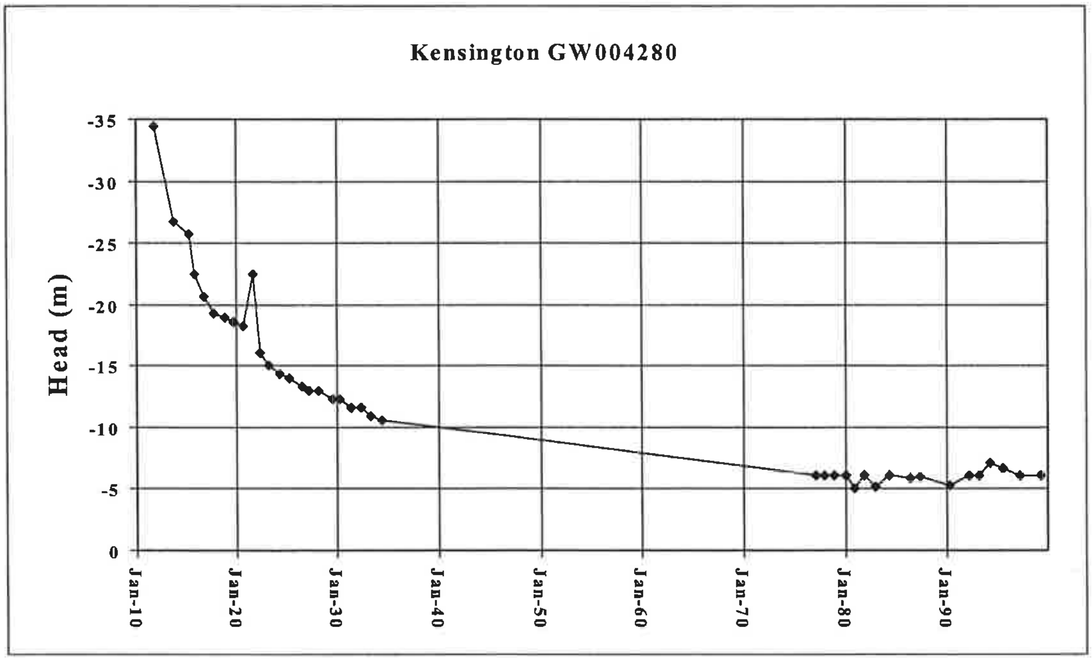


Figure 9: Hydrograph of Kensington, GW004280

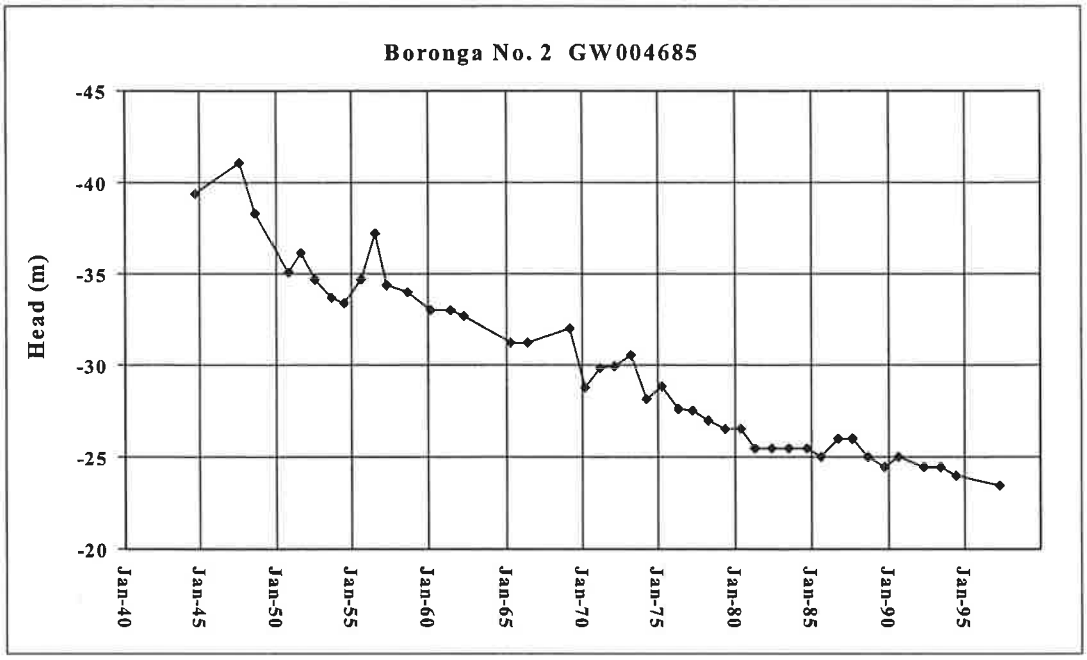


Figure 10: Hydrograph of Boronga No. 2, GW004685

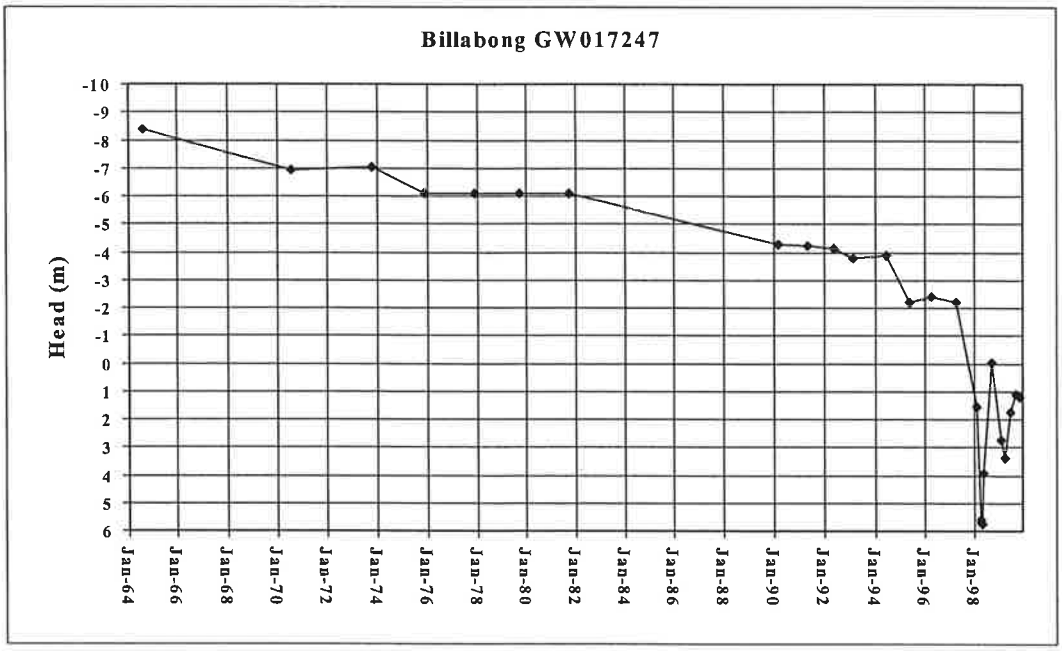


Figure 11: Hydrograph of Billabong, GW017247

3.2 Groundwater Quality

Generally low salinity groundwater occurs in the most widely used aquifers of the Lower Cretaceous - Jurassic sequences (Pilliga Sandstone in the east, Hooray Sandstone in the west). Groundwater quality in the lower artesian aquifers is more variable, but salinity is generally lower than that found in the confining sequences of the GAB. Groundwater salinity generally increases away from the recharge areas (200 mg/L Total Dissolved Salts, TDS) along the groundwater flow path toward the north and west (over 2000 mg/L TDS). The level of total dissolved solids remains low in the main aquifers owing to the inert nature of the aquifer material (GABCC Resource Study, 1998).

GAB groundwater is of the Na-HCO_3-Cl type. Sodium is the dominant cation, which renders the water unusable for irrigation in most places, as water with a high percentage of sodium (expressed as the sodium absorption ratio - SAR) is chemically incompatible with clayey soils, destroying soil structure. A combination of lower SAR groundwater and sandy soils allow irrigation to occur in the recharge areas on the eastern margin of the basin. Sodium concentrations as low as 25 mg/L occur in the recharge areas, increasing progressively to over 1000 mg/L in the far west (GABCC Resource Study, 1998).

Alkalinity (as HCO_3^-) is the dominant anion, however chloride concentrations relative to HCO_3 increase westward. Chloride concentrations are very low in the eastern recharge areas and the Coonamble Embayment (<50 mg/L), but increase steadily to over 1000 mg/L near the South Australian border (GABCC Resource Study, 1998).

3.2.1 Identification of Beneficial Uses

The existing or potential beneficial uses of GAB groundwater need to be identified before setting water quality objectives and developing management rules to maintain those beneficial uses. The identification involves an assessment of groundwater quality; an assessment of existing and planned developments in the GAB in terms of their potential demands for water and the type of water use; and an assessment of the important environmental features that are reliant on GAB groundwater. Beneficial uses can be categorised as follows:

- agricultural water
- raw water for human drinking water supply
- ecosystem protection
- recreation and aesthetics
- industrial water

3.2.1.1 Agricultural Uses

Agriculture is the largest user of GAB groundwater. Agricultural use can be sub-divided into two categories; pastoral (stock) and irrigation. The chief water quality considerations of GAB water for irrigation are total salinity, and the level of sodium relative to other cations (sodium absorption ratio, SAR). The acceptable level of total salts and sodium is very much dependant upon the soil and crop type, hence it is difficult to assign clearly defined levels of suitability. Excessive sodium (high SAR) in irrigation water can adversely affect soil structure. At SAR levels approaching and above 10, clays within the soil become dispersed and puddled when wet, lowering permeability and forming a hard impermeable crust when dry. Generally, groundwater in the northern parts of the Recharge Zone is suitable for irrigation on well-drained sandy soils. Elsewhere in the Basin, although total salinity is often suitable for irrigation, high SAR values prohibit such use.

Stock can tolerate relatively saline drinking water. The quality of GAB water drawn from the most widely used GAB aquifers is ideal for stock watering. Even the more saline groundwater (>10,000 mg/L) from the shallower aquifers is largely suitable for stock use. However, elevated fluoride levels in some areas of the basin pose hazards for stock consumption (Figure 21, GABCC Resource Study, 1998)

3.2.1.2 Town Water Supplies

Groundwater with salinity less than 1000 mg/L is suitable for human consumption, while less than 500 mg/L is desirable. The salinity of GAB groundwater is mostly below 1000 mg/L and is generally suitable for domestic and town water supply. Elevated fluoride levels need to be considered in some cases (Figure 21, GABCC Resource Study, 1998).

3.2.1.3 Ecosystem Protection

Flows from natural artesian springs have sustained important natural ecosystems in areas that are otherwise without any permanent water. Any significant alteration to the quality of the discharging groundwater is likely to have a detrimental impact on the reliant ecosystems.

3.2.1.4 Recreation and Aesthetic Uses

Non -flowing recreation bores are used for spa-bath tourist facilities in Moree. Quality considerations similar to drinking supplies apply to such recreational use, with the additional quality requirement of heated water. Remote communities, landholders and outback tourists also utilise warm artesian water for swimming and bathing.

3.2.1.5 Industrial Uses

Industrial uses of GAB groundwater include mining and a commercial feedlot in the Northern Recharge Zone. Mining is currently a modest user of artesian water in NSW and this is primarily associated with the opal mining in the Lightning Ridge and White Cliffs areas. It is not foreseen that this activity is likely to see any substantial expansion and therefore any significant increase in water usage. Other types of mining are unlikely to occur within the basin due to the substantial depth of artesian sediments. There is potential for the development of petroleum resources in rock strata below the water bearing formations of the GAB. Any such developments are required to undertake a full EIS to ensure minimal impacts.

3.2.2 Existing Contamination Threats

3.2.2.1 Groundwater Vulnerability to Polluting Activities

Groundwater vulnerability mapping is a management tool for the assessment of the susceptibility of a groundwater resource to potentially polluting surface activities. Susceptibility to pollution is a function of natural geological conditions, and while mapping of the GAB has not yet commenced, the vulnerability of the GAB groundwater is generally low owing to the depth and confined nature of the aquifers. However, the Northern Recharge Zone, and in particular where the sandstone beds outcrop, is more susceptible to contamination. That said, vulnerability mapping completed for the Gwydir River Catchment has classified the outcropping GAB sediments to be at low to moderate risk, reflecting the deep watertables that occur in the Intake Beds.

3.2.2.2 Inter-Aquifer Contamination

An existing contamination threat, applicable across the GAB in NSW, is the possibility of inter-aquifer leakage, resulting from the deterioration of bore casings. This situation may lead to waters of differing quality mixing and spoiling good quality water. The artificial interconnection of aquifer systems through bore construction can pose a hazard for aquifer quality in instances where a flow potential from a more saline aquifer to a less saline aquifer exists. Fortunately in most cases the fresher water found in the deeper aquifers is under higher pressure than the shallow saline groundwater.

Cement grouting procedures, as outlined in Minimum Construction Requirements for Water Bores in Australia (ARMCANZ, 1997) must be following in the construction of artesian bores. Cement grouting seals the annular space between the casing and the borehole, preventing the transfer of water between aquifers of different pressures and quality.

3.3 Groundwater Dependant Ecosystems

In the context of the GAB in NSW, the term ‘groundwater dependent ecosystems’ usually refers to artesian springs and their immediate environments, which are totally dependent on GAB groundwater for survival. However, there are many broader ecosystems in the GAB, which are largely or partially dependent on groundwater. This degree of dependence may vary over time with the change of seasons, or in response to longer-term natural drought cycles. In addition to the organisms living solely within the springs, these ecosystems originally included migratory species of animals and people.

Native plants living in the GAB may be physiologically adapted to tolerate drought or may be short-lived species that germinate after rain and set seed. Native animals have adopted various mechanisms to cope with the lack of water and the climatic unreliability: these include migration, dormancy or obtaining water from food. Integral to the survival of many species through drought times have been the locations where artesian water naturally discharges to the surface. These locations are known to support a variety of groundwater dependent ecosystems.

The advent of bores tapping the artesian aquifers introduced a permanent water supply in formerly arid areas. Water from these bores is typically distributed via open bore drains - often 10's or 100's of kilometres long - and numerous stock troughs and earth tanks. This widespread source of water has led to new species of plants and animals being introduced, and marked changes in the number and types of native animals present. (Landsberg et al. 1997)

Specifically, those animals adapted to living without permanent water have generally had their habitat and numbers reduced, while water dependent species - including feral animals - have generally seen their habitat and numbers increase. Today, most of the groundwater discharging from the Basin is used for watering sheep and cattle, to supply human needs on pastoral stations and in towns, and more recently the mining industries. In a strict sense, the native and introduced plants and animals, and all the people now using bore water are part of a groundwater dependent ecosystem.

3.3.1 Springs

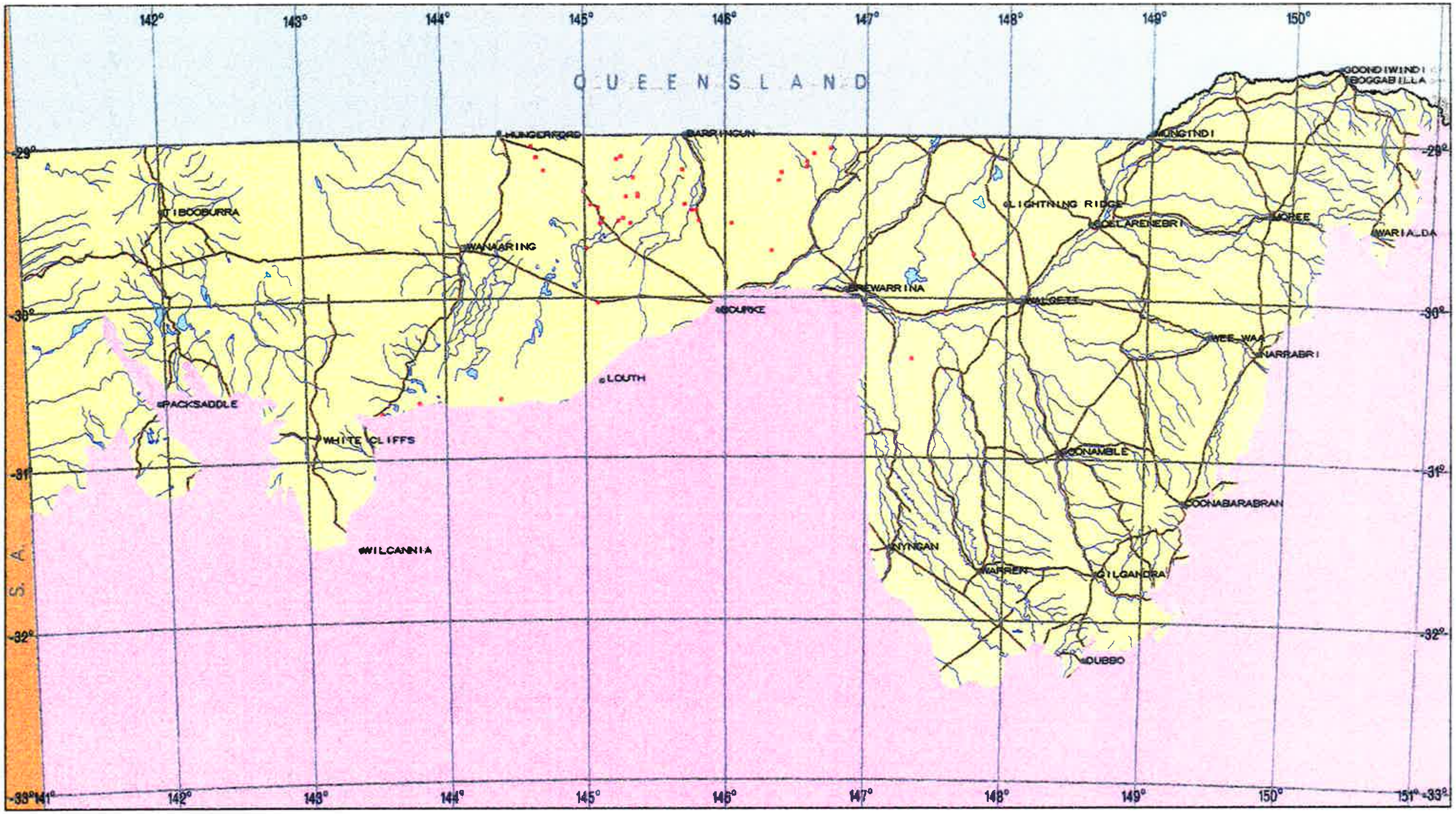
Natural artesian springs in the GAB are probably among the rarest habitats in Australia, and are geologically, geomorphologically and biologically important. (Pickard, 1992) The availability of GAB water from these springs has played a major role in determining the natural and cultural history of the Basin. Artesian springs are generally referred to as 'mound springs' but some are depressions in the surface, and others are more accurately called 'mud springs' as the flow rate is only enough to maintain a muddy patch at the surface. (Pickard, 1992)

There are approximately 45 sets of artesian springs associated with the GAB in NSW (**Figure 12**). The decline in artesian flows and pressures over the last century has led to a substantial reduction in these ecosystems, and only some 30 of these still have permanent seeps or retain slight flows. (Pickard, 1992).

3.3.2 Rangeland Ecosystems

The land over the NSW GAB is mostly arid or semi-arid plains with few sources of permanent water. Average annual rainfall ranges from about 600 mm in the east to less than 150 mm in the far west, but is significantly variable. Vegetation types vary according to climatic and soil characteristics. Tussock grasslands and woodlands predominate in the eastern half of the Basin, with some patches of forest in the south east. The western half of the Basin is characterised by low woodland and shrubland.

The Great Artesian Basin's greatest asset in the dry and remote grazing lands is the pressure of the confined aquifers, which causes the groundwater to flow through bores to the surface. This



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GREAT ARTESIAN BASIN (NSW)

ARTESIAN SPRINGS

SCALE
50 0 50 100 150
kilometres

LEGEND

- ■ Location of Artesian Spring

Figure 12

groundwater from the basin is directly responsible for the agricultural development of the area and is the main supply for stock, domestic and town water over much of the area.

Before European settlement the types of plants and animals present in the GAB reflected the mostly arid conditions. The introduction of agriculture significantly changed the land use, and in most areas the ecosystems. Droughts were previously experienced as a lack of water that forced surface-water-dependent animals to move from the rangelands. The introduction of permanent water allowed stock and native animals to remain, and droughts came to be experienced as shortages of feed. As a result, the land was overgrazed and required longer periods to recover after the drought. Also, those species adapted to living without permanent water sources have been disadvantaged, some severely. These disadvantaged species may represent up to 38% of the native species originally present (Landsberg, et al., 1997). This is therefore a major issue in terms of Australia's national commitments to conserve biodiversity.

Biodiversity is now being recognised as having considerable benefits for agriculture. Increased numbers and types of micro-organisms in the soil can improve pasture productivity, and the retention or restoration of remnant vegetation on farms can improve animal performance through shade and shelter effects, and through providing habitat for birds and insects which prey upon pests (Francis, 1998). There may be other, as yet unknown, benefits and it is therefore desirable to protect and enhance biodiversity on farms, particularly through increasing natural habitat.

One already identified issue emerging within management of GAB groundwater is the potential for removing permanent watering points to preserve and enhance biodiversity in formerly waterless areas. These areas can be opportunistically grazed in good seasons and removed from grazing during poor seasons when most damage from grazing occurs. The CSIRO has already initiated research in this area and there is the possibility for it to be incorporated into the work of the GABAC and the NSW Cap & Pipe the Bores program.

Pastoralism occupies almost all of the rangelands in NSW and therefore conservation of natural resources will depend largely on the management practices of pastoralists. Individual property owners can assist conservation by using conservative stocking pressures, managing critical habitats (eg. fencing waterholes), and managing high conservation value areas on adjoining properties as a unit. For example, by periodically turning off livestock water in these areas on all adjoining properties, large areas could be periodically kept free from livestock. In this way, natural vegetation and animals can recover from grazing pressure before stock are reintroduced.

Other significant issues in the GAB are the creation of artificial wetlands associated with bore pools and bore drains, and the discharge of drains to natural watercourses. These wetlands are used by native species but favour the water dependent species at the expense of non-water dependent species, and also greatly benefit feral species. Artesian water entering watercourses and natural wetlands can impact upon the ecology by changing the water regime and the salinity levels.

Significant changes in GAB ecosystems have occurred as a direct result of the use of artesian water on pastoral properties, and particularly as a result of the distribution of this water via open bore drains. Water with a high Sodium Absorption Ratio (SAR) can also have significant negative impacts on soil structure and salinity. This is particularly important when it comes to irrigating with GAB groundwater.

3.3.3 Aquifer Ecosystems

Research from other groundwater systems around the world and in Australia is providing important information about organisms living within aquifers. In some instances, organisms living between the particles of the aquifer actually play a role in maintaining porosity, which affects storage and throughflow of water. In other situations, organisms have been shown to have existed unchanged since before geological processes formed the separate continents of Australia, Antarctica and Africa. As our knowledge of the GAB is far from complete, management decisions must err on the side of caution until we can be sure of the consequences of any actions that may damage or destroy these aquifer ecosystems.

3.3.4 Cultural Significance

There is evidence of the existence of Aboriginal use of the land above the GAB for many thousands of years. The water from natural discharges in the GAB supported plants and animals that were harvested by Aboriginal people, and enabled settlement of some areas. Flowing springs were especially important when surface water was not available. The GAB was also incorporated into the spiritual and cultural beliefs of some of the communities that inhabited the area. (GABCC Resource Study, 1998).

Since the turn of the century, GAB water has been essential for the development and maintenance of pastoral enterprises. There are many sites associated with this historical development that may be of cultural importance to indigenous and non-indigenous Australians alike.

4 Groundwater Management and Use

4.1 History of Groundwater Management

The introduction of groundwater regulation for the GAB in NSW has been covered in the GABCC Resource Study (1998), and is described briefly here. Several Acts of parliament were introduced around the turn of the century; however, it was not until the introduction of the *Water Act of 1912* that some control of the GAB was achieved. The Act set bore completion standards and required the licensing of bores and wells so that appropriate hydrogeological data could be acquired and maintained by the government. The Act required the licensing of all bores deeper than 30 metres, in the western half of the State, but was amended in 1955 to include all bores in the GAB. A requirement was introduced in 1965 that all distribution from new stock and domestic bores be piped.

Although most bores are privately owned, many belong to Bore Water Trusts with several properties sharing the water from one or more artesian wells. Under the terms of the *Water Act (1912)* these are operated by two elected Trustees plus an official government Trustee. The government exercises a supervisory and advisory role in the management of the Trusts.

In the early stages of development, the purpose of almost all GAB bores was for watering stock via open bore drains fed by free flowing bores. Most were constructed prior to the implementation of the licensing requirements; hence most of these bores are unlicensed, although most are registered with the NSW government.

Town, mining and recreation licences have been granted on a needs basis, and more recently, irrigation licenses have been issued in areas with suitable water quality and soil types. An embargo on further groundwater licences (apart from a number of exemptions) was imposed in the North Star - Croppa Creek area in 1995, and was extended to include the rest of the eastern recharge area in 1998. This was further extended to include the entire NSW portion of the GAB in December 1999 (NSW Government Gazette, 17/12/99).

Under the current embargo, no further applications for groundwater licences can be made apart from several exemptions, which include stock and domestic purposes, town water supply, and a number of industrial and commercial purposes under 5 ML/year.

4.2 Current Groundwater Allocation and Usage

Groundwater bores in the GAB fall into 2 broad categories:

- stock and domestic, either unlicensed, or, licensed in perpetuity, with or without a volumetric allocation
- “high yield” (irrigation, mining, recreation, town water supply) mostly with a renewable license and volumetric allocation.

The distribution of stock and domestic, and "high yield" bores is shown in **Figure 13**. "High yield" bores are restricted mainly to Zone 1, where water quality is suitable for irrigation. The remaining "high yield" bores are located in Zone 2; for recreation use at Moree and mining at Lightning Ridge. The greatest concentration of stock and domestic bores is found in the centre of the Coonamble Zone (Zone 2) and the throughout the Warrego Zone (Zone 3).

Table 2 summarises bore allocation and usage data that is currently available. With many bores being unlicensed, there are significant gaps in information. The compilation of data for this resource summary has enabled the identification of these information gaps, and a process is underway to gather outstanding data. Therefore the numbers should be treated as indicative only, and are likely to change marginally as better data is obtained.

Table 2: Summary of NSW GAB Bore Status 1999

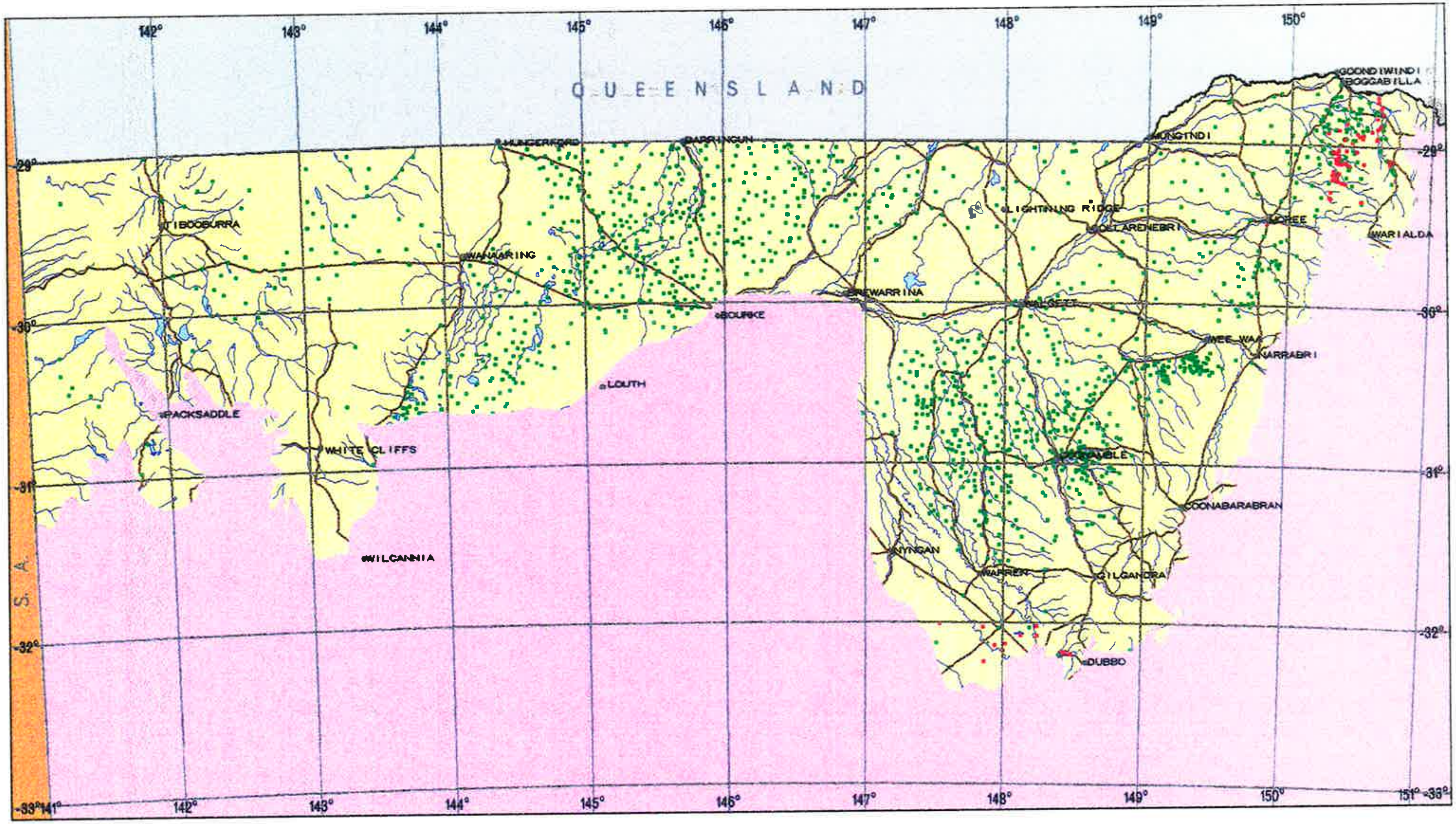
	Recharge Zone	Coonamble Zone	Warrego Zone	Central Zone	**Total**
Total Bores	265	613	468	71	**1,417**
Free Flowing Bores	20	372	208	17	**617**
Non Flowing Bores	245	241	260	54	**800**
Free Flowing Extraction (ML/year)*	1,116	72,582	20,803	7,558	**102,059**
Stock and Domestic Bores	194	607	468	71	**1,341**
Irrigation, Industrial, Recreational Bores	70	6	0	0	**76**

* Estimated minimum flows for zone. Data taken from latest available flow record post 1986. Note not all flowing bores will have appropriate data and therefore will not be included. These calculations do not take pumped extractions into consideration.

Prior to the implementation of the embargo on high yield licences in 1995, 26,684 ML/yr had been allocated to 76 properties for irrigation in the northern part of Zone 1. In addition, 57 outstanding licence applications received prior to the moratorium were offered 60 ML/year per property to provide drought relief. As of June 1999, 45 licenses with an allocation of 5,462 ML/year had been cancelled, leaving 88 licenses with a total allocation of 24,642 ML/year.

Nine irrigation licenses have been issued in perpetuity, and have no volumetric entitlement. These licenses are to be converted to a volumetric licences on the basis of maximum historical usage, to a property maximum of 486 ML/yr where appropriate.

Annual irrigation usage is low. Annual usage was 2,072, 6,569, and 5,588 ML/over the past 3 irrigation seasons. As of June 1999, 58 bores have been constructed, of which 40 are equipped with pumps. Eight bores are still free-flowing, and are estimated to extract 449 ML/year.



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GREAT ARTESIAN BASIN (NSW)

BORE LOCATIONS

LEGEND

- 🟩 Stock and Domestic Bore (1360)
- 🟥 Irrigation, Industrial, Recreational Bore (76)

Figure 13

Five high yield licenses have been issued for the recreational spa industry in Moree (Zone 2), with a total allocation of 996 ML/year. Four of the licensees are active users, with the fifth licensee expected to commence usage within the next year. The mining industry at Lightning Ridge has two bore licenses with a combined allocation of 200 ML/year. Combined usage is less than 50 ML/year.

4.3 Cap & Pipe the Bores Program

More than two-thirds of the water currently extracted from the GAB is wasted by deteriorated or uncontrolled bores and a network of outmoded, wasteful bore drains (see **Figure 14** for bore drain locations). The control of this water through capping and piping is essential to any successful management outcome in the GAB.

In NSW, the Cap & Pipe the Bores program encourages landholders to undertake these works by providing grants for bore rehabilitation and the replacement of bore drains by efficient piped systems. However, when introduced in 1993, the incentives were insufficient to attract the higher flowing bores and it was not until the grants were increased in 1997 by two other initiatives, Drought Regional Initiatives and West 2000, that the program became strategic.

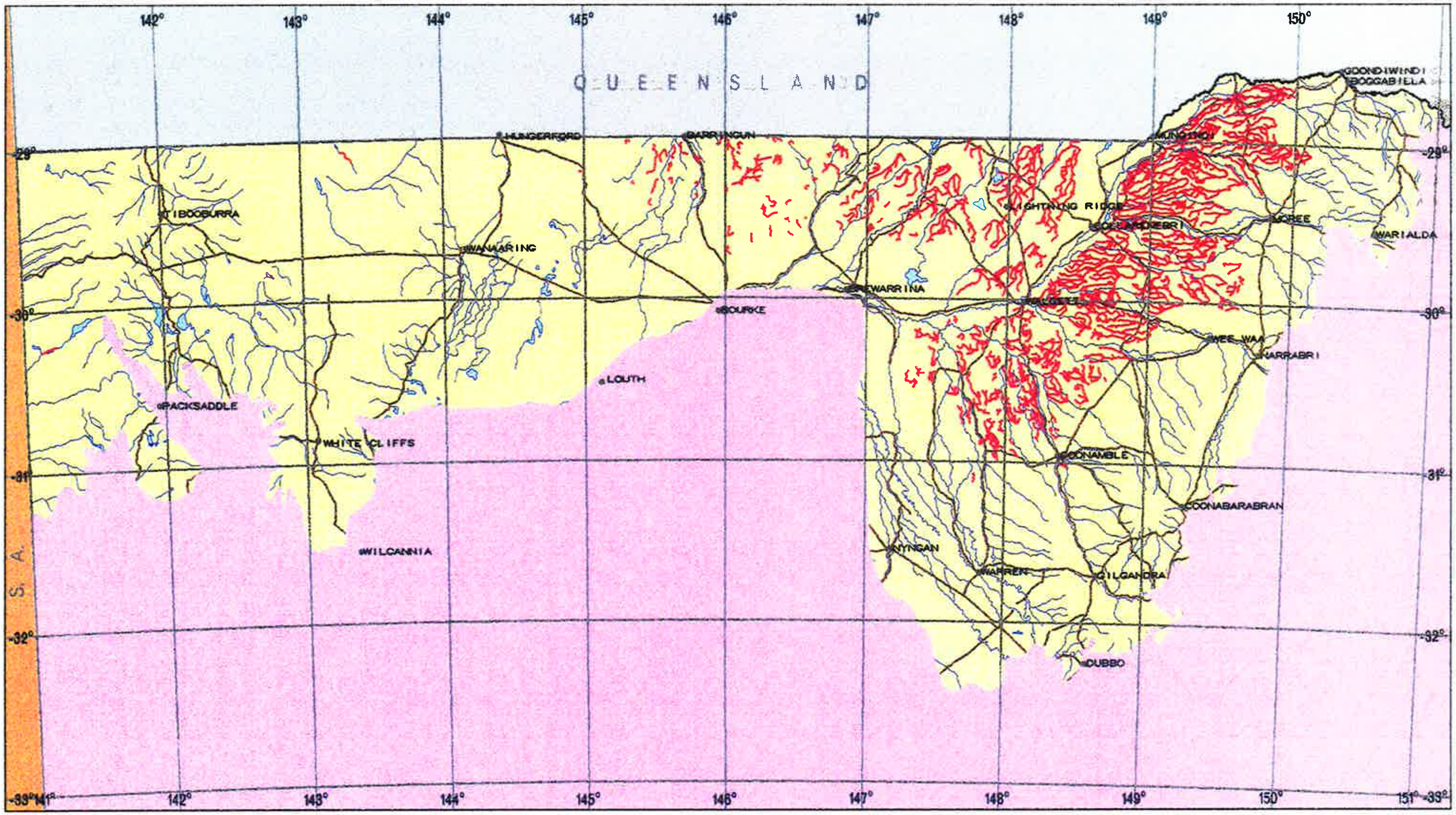
To build on this, a Strategic Plan has been developed to optimise the economic, environmental and community benefits from the funds invested. It will be implemented in three 5-year phases with a mixture of incentives and disincentives and targets the 180 bores flowing in excess of 5 litres per second and those causing excessive environmental damage.

There will be an annual call for participation in the program and applications will be prioritised. This priority will be achieved by a "multi-criteria analysis" of each application received based on pressure restoration, flow rates, water saved, bore drains deleted, water quality, impact on mound springs, habitat, property planning and cost.

The Commonwealth Government is providing $31.8M over the next 5 years to a Great Artesian Basin Sustainability Initiative for the rehabilitation of the GAB. With this to matched by State funds, incentives can be set at levels sufficient to encourage the targeted bores into the program, which is purely voluntary.

Over the next 5 years it is hoped to cap and pipe 60 of the targeted bores, restoring artesian pressure to acceptable levels, replace more than 2000 kilometres of bore drains and reduce wastage by 15,000 megalitres annually.

Some details of the program to date are outlined in **Tables 3(a), 3(b) and 4**.



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GREAT ARTESIAN BASIN (NSW)

BORE DRAINS (1997)

SCALE
50 0 50 100 150
kilometres

Figure 14

Table 3(a): Cap & Pipe the Bores Financial Details; Allocations ($000):

Year	**C&PTB**		**D R I**		**West 2000**		**Total**	**Total**	**Total**
	NSW	**C'wlth**	**NSW**	**C'wlth**	**NSW**	**C'wlth**	**NSW**	**C'wlth**	**Gov't**
93/94	445	250	-	-	-	-	445	250	695
94/95	538	250	-	-	-	-	538	250	788
95/96	868	250	-	-	-	-	868	250	1118
96/97	1798	250	-	-	-	-	1798	250	2048
97/98	1765	250	250	250	250	250	2265	750	3015
98/99	1538	250	250	250	250	250	2038	750	2788
99/00	1538	Tba	0	0	200	200	1738		

Note: Drought Regional Initiative funding available over 2 years

West 2000 funding available over 3 years

Table 3(b): Cap & Pipe the Bores Financial Details; Expenditure ($000):

Year	**C&PTB**		**D R I**		**West 2000**		**L'hldrs**	**TOTAL**
	NSW	**C'wlth**	**NSW**	**C'wlth**	**NSW**	**C'wlth**		
93/94	156	250					449	855
94/95	264	250					806	1320
95/96	315	250					700	1265
96/97	470	250					964	1684
97/98	893[1]	250	141	141	0	0	1228	2653
98/99	1793[2]	250	359	359	100	100	1504	4465

Note: [1] - unspent $872,000 carried over and available in addition to 98/99 allocation

[2].- unspent $615,000 carried over and available in addition to 99/00 allocation

Table 4: Cap & Pipe the Bores Achievements:

Year	**Bores capped (No.)**	**Bores piped (No.)**	**Bore drains replaced (km)**	**Water saved (ML/year)**
93/94	6	5	124	466
94/95	6	5	27	351
95/96	8	6	113	267
96/97	6	7	113	440
97/98	10	24	805	5934
98/99	10	10	118	579
Total	46	57	1198	8037

Note: Works are still in progress in some of these projects.

5 Monitoring and Research

5.1 Groundwater Pressure/Flow Monitoring

Prior to 1982, three teams were employed by the Department to gauge artesian bores; two based in Moree, with the third in Bourke. In 1982, the gauging teams were reduced to two, and from 1989, a single team has operated out of Moree.

A gauging team consists of a bore gauger and an assistant whose role is to record flow, pressure, temperature and field chemistry data. In addition, they check on the correct location of the bores, monitor the condition of headworks, inspect the method of flow distribution and storage, identify excessive wastage of water, and carry-out minor maintenance.

When the gauging teams were reduced to one in 1989, a network of 80 bores across the state was selected to be monitored annually. Many of these bores were subsequently found to be unsuitable for monitoring (unlocatable, destroyed headworks etc.), and the network was reduced to 53 bores, which is the current core monitoring run (**Figure 15**).

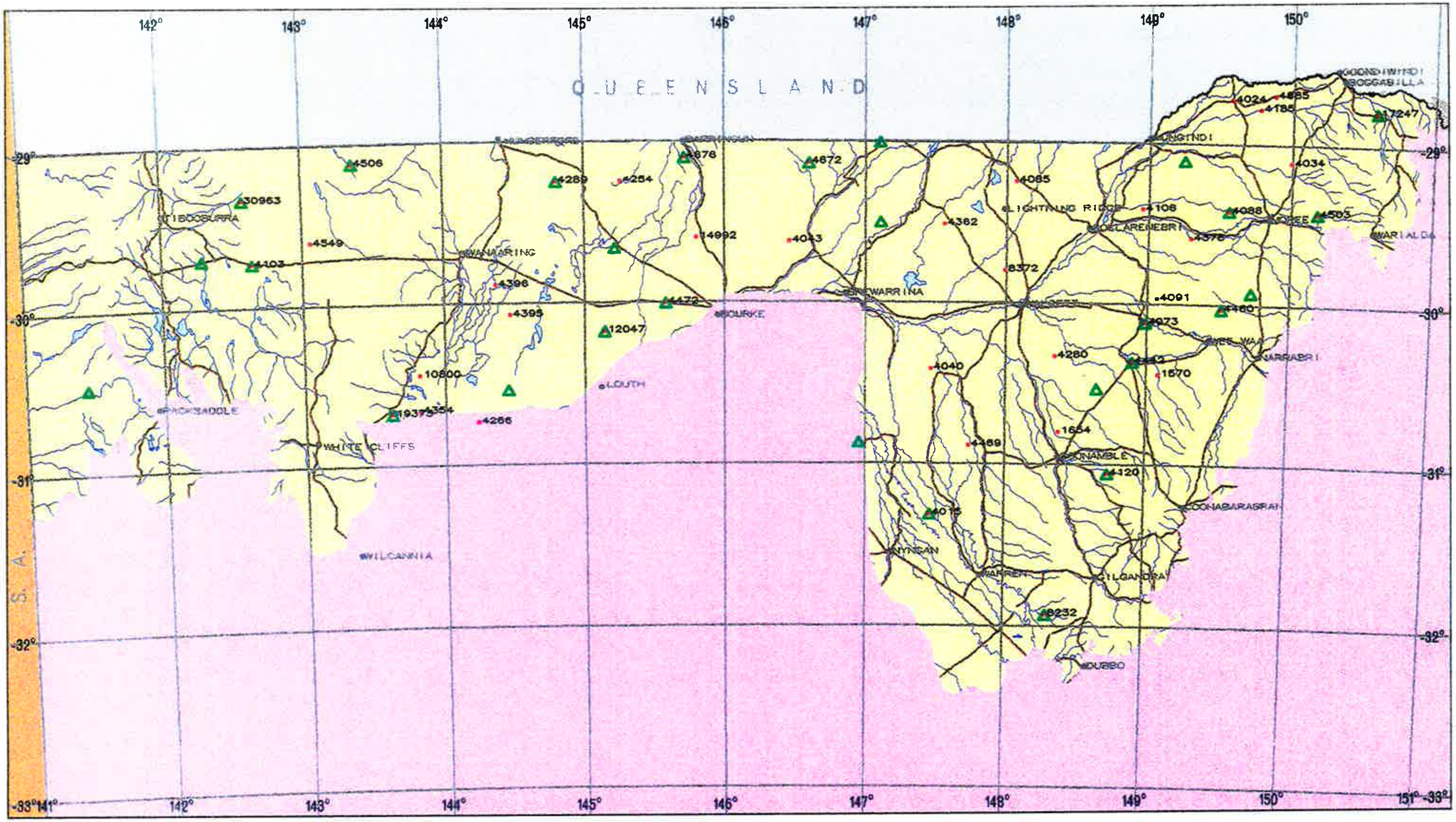
Additional demands for water pressure information has widened the monitoring network to include:

- all bores within a 50 km radius of Lightning Ridge (34 bores)
- newly constructed bores (typically around 5 per year)
- bores to be capped & piped (typically around 8 per year)
- flowing and cease-to-flow artesian bores in the Moree and north Recharge Zone area (46 bores)
- irrigation bores in the northern part of the Recharge Zone (58)
- non-artesian stock and domestic bores in the Northern Recharge Zone
- Gurley Station hot-spot (11 bores)
- Other special or one-off requirements (typically 5 – 10 per year)

These additional demands have grown in an ad-hoc manner, stretching monitoring resources and causing delays to the monitoring of the core network.

An assessment of the monitoring network for the whole GAB has been recently completed (Sinclair et. al., 2000). It found that a network of 202 bores will be sufficient for hydrologic monitoring at a Basin-wide scale. Of the 202 key bores, 32 are located in NSW (**Figure 15**), and are to be mandatory inclusions in the State monitoring network. Clearly however, more bores are needed to adequately cover state and local requirements.

Guidelines for a revised bore monitoring network have been outlined in the DRAFT NSW Great Artesian Basin Management Plan (2000). A revised monitoring network following the proposed guidelines should be formulated and implemented within the coming months.



GREAT ARTESIAN BASIN (NSW)

GAB MONITORING IN NSW

SCALE

50 0 50 100 150

kilometres

LEGEND

- 🟥 Current GAB bores monitored annually (with number)
- △ Proposed keysites for basin wide monitoring

Produced by
Surface and Groundwater Processes Unit,
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LAND & WATER CONSERVATION

Figure 15

5.2 Water Usage Monitoring

Accurate knowledge of the volume of water extracted from the GAB, whether free flowing or pumped, is required for the sustainable management of the GAB. Usage data, in conjunction with water level and pressure data, can be used to develop aquifer sustainability calculations. Current usage monitoring is limited to the high use irrigation bores in the Yallaroi/North Star area of the GAB intake beds, town supply bores and several industrial bores in the Lightning Ridge area. It is a requirement under the Water Act that all bores with renewable licenses have flow metres for measuring water use.

Usage figures for both free-flowing and non-flowing stock and domestic bores have not been collected. Most of the bores in the GAB are stock and domestic, hence are unlicensed with no attached conditions, including the requirement to provide usage figures. Estimates can only be obtained by extrapolation of flow rates measured by those stock and domestic bores incorporated in the State's GAB bore monitoring network.

5.3 Groundwater Quality Monitoring

Current monitoring of the quality of GAB groundwater in NSW is limited to the measurement of field parameters (pH, EC and temperature) whenever a bore is monitored for flow/pressure. This information is stored in the DLWC's Groundwater Data System.

In the early 1990s, a sampling and analysis program was initiated, whereby each monitoring bore was to be sampled every 5 years, and a suit of chemical parameters analysed. An initial monitoring and sampling run took place, however the program has ceased due to the diversion of funds to other priority projects.

5.4 Research Activity

5.4.1 Recharge and Flow Processes

A greater understanding of the recharge processes and groundwater flow characteristics is the key research requirement for the GAB. Recharge is the single most important parameter, which must be reliably estimated or measured in order to manage the GAB groundwater system in a sustainable manner. A synopsis of research to date is provided in the GABCC Resource Study (1998) and a brief overview of key projects is given below.

Recharge research has particular sub-regional importance to the areas affected by intensive groundwater extraction in the Border Rivers/Intake Bed region (northern part of Zone 1). The lack of knowledge of recharge processes and fluxes (particularly across the Goondiwindi Fault) has lead to uncertainties regarding the impact of such groundwater allocations to other users in the Basin.

To address the lack of understanding, a project is under development by the DLWC and other research partners . The objectives of the project are to:

- enable development of allocation policies that will place groundwater use within the sustainable yield of the NSW intake beds.
- determine the degree of hydraulic connection between the eastern and western sides of the Goondiwindi Fault so that future regional impacts on down-gradient users can be predicted from changed allocations to users in the intake beds.
- provide accurate recharge measurements to improve the basin wide groundwater simulation model being developed by the GAB Technical Working Group.

5.4.2 Groundwater Modelling, Intake Beds (northern Recharge Zone)

A computer model was developed in 1996 to simulate the impact of potential increased groundwater extraction, brought about by increases in the volume of groundwater licensed for extraction for irrigation supply in the GAB Intake Beds. It has been recognised that this modelling work needs to be taken further, however current data is insufficient to extend the study. Monitoring activity is to be increased in the coming years to allow for a better modelling outcome.

5.4.3 Basin-wide model

A Basin-wide model for the GAB is in its final stages of development by the Bureau of Rural Sciences, and in its present form, simulates the main exploited aquifer (Hooray Sandstone/Cadna-Owie Formation and equivalents, including the Pilliga Sandstone) explicitly and the vertically adjacent aquifers (Adori sandstone and Winton/Mackunda Formations) implicitly by their leakages. Named GABMOD, it solves for groundwater pressure by discretizing the Basin into 5x5 km cells (producing a model grid with 359 rows and 369 columns) and numerically solves the groundwater flow equations within each cell. Its accuracy is limited to the 5x5 km cell size, thus it is truly regional in character. GABMOD is intended to underpin future regional management in the GAB. It will address these and other questions:

- What are the groundwater inflows and outflows, and how do they vary in time and space?
- What are the variations in groundwater pressures and discharges over time?
- What will be the effect on flow and pressure in nearby bores and springs if large-scale pumping is introduced for mining or other developments?
- How will capping and piping certain bores impact on pressures and discharges in nearby bores and springs?
- Which areas benefit most from the Bore Rehabilitation Program?
- What are the down-gradient effects of groundwater withdrawal for irrigation or other developments in and near the intake beds?

5.4.4 Hydrochemical Study

A hydrochemical study undertaken by AGSO identifies three major phases of the chemical evolution of GAB groundwaters and provides an understanding of the spatial distribution of major and minor dissolved elements, and certain of their isotopes. The youngest phase produced the through-flow pattern that currently exists in the Basin. Incoming recharge water associated with this youngest phase has displaced older stagnant phase waters to distances of several hundred km from the Basin margins. Results will be published in an AGSO Bulletin to be released during 2000.

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Appendix A: Notes on the Construction of the NSW GAB Maps

General Notes

The GAB boundary is taken from the BRS derived GAB boundary and as accepted by the GABCC. However it is noted that some bores identified as GAB bores plot outside the accepted GAB boundary. Further investigation of these bores is required to determine their fate.

Bore Status

Bores identified as accessing water from GAB sediments, regardless of flow status have been included in the dataset. Bore records were collated from old bore cards, the microfiche dataset, and those bores which regional staff identified as a GAB bore. However only those bores that had the location details could be shown on the map. Bores identified by regional staff as being used for a purpose other than for stock and domestic are tagged as irrigation, recreational, industrial.

From this list of known GAB bores an assessment was made on each bore as to its flowing or non-flowing status. Flow status was determined using the following criteria.

- Bores for which a recent flow measurement greater than 0.1L/s was identified as a flowing bore.
- Ceased to flow bores (CTF) bores which may have once flown and now having ceased to flow were identified as non flowing bores.
- Bores from which no flow or head was ever recorded against the bore, ie. are believed never to have flowed were identified as non flowing bores.
- Where bores may have had a small flow or trickle <0.1L/s at the last reading, or may not have had a recent gauging. An assessment was made on the bore as to its flow status depending on trend of previous gaugings and time since last gauging took place.

Whilst general patterns can be seen from the Bore Status (1999) plan it is obvious that some bores are indicated as being non flowing amongst flowing bores and vice versa. Whilst no work has been carried out to specifically investigate this phenomenon some possible reasons for this include;

- Areas are low flow areas, bordering on flow non flow,
- If the bore is located on a topographic high the flow from the bore can be affected,
- Damage to the bore, or collapse of the bore may be a contributing factor
- Variations in basin structure and or aquifer parameters,
- Increased extraction from neighbouring bores.

Summary of NSW GAB Bore Status 1999

	Recharge Zone	Coonamble Zone	Warrego Zone	Central Zone	**Total**
Total Bores	265	613	468	71	**1,417**
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Stock and Domestic Bores	194	607	468	71	**1,341**
Irrigation, Industrial, Recreational Bores	70	6	0	0	**76**

* Estimated minimum flows for zone. Data taken from latest available flow record post 1986. Note not all flowing bores will have appropriate data and therefore will not be included. These calculations do not take pumped extractions into consideration.

The numbers in the above table are estimates of bores which fall within the AGSO defined GAB boundary (1997), and the status of which is an interpretation based on the most recent information available from the Groundwater Data System (GDS) for the bore, 1999.

Some 43 GAB identified bores fall outside the GAB boundary 35 of these are non flowing bores with 8 of the bores identified as being flowing.

NSW Great Artesian Basin Bore Drain Map, (1999).

The bore drain map was produced to give an indication of the distribution of bore drains within NSW. The bore drains were digitised from 1:50,000 and 1:100,000 scale topographic sheets from LIC.

The following rules were used as a guide to the inclusion of drains for digitising.

- The bore drains must commence from a known artesian (flowing) bore.
- The drains must be shown on the LIC mapping.
- The drains shown from the LIC mapping was cross-checked with the original bore trust maps. If a discrepancy existed between the location as shown on the bore trust maps and the location shown on the LIC maps, then the LIC maps were deferred to. If a drain was shown on the original bore trust map and not on the recent LIC mapping, then it was considered that the drain was no longer in use and was not included.
- Watercourses were only included if shown to be used on trust maps. Where the bore drain ends at a water course, the water course was not included, however if the water course was used to convey the water for some distance before being directed back into a drain proper then it was included.

- Where it was known that bore drains had been replaced by piping the bore drains previously servicing that bore were not included.

Table A1: Bores which have had bore drains replaced by piping prior to 1997 (L Blanch pers. comm.)

Bore No.	Bore Name	Bore No.	Bore Name
GW004537	Tunda	GW004204	Gil Gil
GW004340	Milroy	GW004379	Munna Munna
GW004109	Come by Chance No. 2	GW004776	Wapweelah No. 6
GW004158	Oaks	GW004241	Haddon Rig No. 2
GW004482	Terrigal	GW017686	Carwell No.4
GW018220	Wycombe	GW008388	Minoru
GW004342	Marlow	GW021391	Far West
GW004681	Burrawang No.3	GW004621	Wingadee No.4

Total length of bore drains as indicated on the map is 8,860 km.

It is worth noting that the density of bores is inversely proportional to the distribution and frequency of bore drains. The reasons for this includes;

- The basin is deeper in these parts and the cost of drilling is expensive necessitating the formation of trusts and pooling of resources.
- The land is relatively flat in comparison to other areas allowing the drains to be successfully operated.
- The areas of drains corresponds with areas where higher flows are available facilitating the use of drains to move the water longer distances.

NSW GAB Monitoring

The bores, shown on the accompanying map, indicate only those bores that are currently annually monitored in NSW, and where;

- The bore is locatable;
- The headworks are in a condition suitable for collection of flow and head/pressure readings.
- The bores form part of the 1986 monitoring review in which 68 flowing bores, and 12 non flowing bores were identified for annual monitoring on the basis of 4 GAB bores per 1: 250,000 map sheet.

Bores which could not be located, or where headworks were in poor condition were not included.

Of the original bores that were identified for annual monitoring 52 are currently monitored annually. Of these 52 bores only 42 are suitable for continued monitoring, as the headworks of the remaining bores are in such disrepair that it is not possible to carry out the required monitoring tests. Attention is required to the headworks of all monitoring bores to ensure continued monitoring.

This map does not include those bores monitored outside of the formal monitoring network. Additional monitoring of GAB bores is undertaken of bores in areas where increased extraction is occurring or where investigations into the GAB are required, and is carried out on an as needs basis- Hot Spot Management practice.

Basin Wide Monitoring

A review of the monitoring network has been undertaken at a basin wide scale to identify the minimum number of bores necessary to allow accurate construction of head distribution maps for the basin. The head distribution maps are to be used to help identify pressure restoration or declines and assist in modelling of future impacts under different scenarios.

The study has identified as a minium, some 202 locations throughout the basin to produce the desired head distribution maps, which if adopted has the potential to reduce the costs associated with the current practice of monitoring of over 600 bores. Other recommendations of the report include;

- Measurement of a minimum number of parameters EC, pH and flow as found
- Coordinated collection of the data, all states to monitor nominated basin wide bores within the same three month period.

It is expected that this minimum number of 202 bores will increase slightly to include some bores along the edges of the basin in Queensland and South Australia, which were not included in the original dataset used for the optimisation exercise.

The proposed basin wide network does not intend to replace the need for the states to monitor specific bores for specific issues. However it provides a sound scientific basis for the selection of a minimum number of bores required to produce an accurate head distribution map.

Whilst the location of the key sites monitoring bores are modelled on existing bores, the actual bore chosen as a key site bore is not rigid, with selection of the final bore being dependent on headwork conditions, access, and existing monitoring requirements.

The optimisation exercise has identified 29 bores in NSW are required to provide the head data information to produce an accurate head distribution map.

Notes on NSW Great Artesian Basin Head Differences Map

The maps are an attempt to gain an appreciation of the rate and distribution of changes in head from whence the bore was first gauged and its most recent pressure gauging. The first and last head readings were used in order to gain the greatest head difference for that bore. The maps are at best a general indication only of the distribution and range of variations in head over time.

These maps are based on all available data from the Groundwater Data System GDS, which had GAB pressure data readings. The pressure data was thence converted to a head in metres and corrected for temperature variations to 25°C, to allow for a real change in head to be compared between bores.

The conditions used to identify bores which could be used to construct the head differences map were based on those bores that had a head reading prior to 1980 and with a head reading post 1980. This resulted in filtering the data set down to just over 250 bores that had a pre and post 1980 head values. As can be seen from the maps the distribution of these bores is not even, resulting in areas which could not be easily interpolated by the contouring package.

Some care is required when attempting to draw any conclusions from the maps based on the following considerations.

- There was no condition, or specific date criteria, placed on the dataset to constrain the period between the two heads used to determine the head differences for the map apart from the condition that there is a pre 1980 head and post 1980 head reading. Without head readings taken for bores at the same time it becomes very difficult to make comparisons between bores. It was not possible to restrict the data to only those bores that had measurements on specific dates and still have sufficient data points to construct the maps. The situation can therefore arise where one bore may have as its first head reading being taken in 1930 with its last head reading in 1997 (24,600 days) and the bore next to it having its first reading taken in 1970 with its last reading taken in 1987 (6,200 days). This will result in two bores next to each other having differences in heads based on when the two readings where taken.
- The ideal situation is where for each bore you have the heads taken on the same date to allow for true comparisons to be made, as indicated there was insufficient data to allow this. An attempt to calculate head difference using two five year periods 1915 –1920 and 1983 –1988 yielded only 12 bores which had records for both these periods.
- There is an uneven distribution of bores.
- The range used to differentiate between head differences is based on those bores where there was a rise in head and those bores where there was a falling head over time. Falling head ranges approximately correspond to 25 percentiles for that data set.

Whilst the dataset is inconclusive it is worth noting that some bores in localised areas show rises in head between the first reading available pre 1980 and the latest reading post 1980. These rises and reductions in pressure decline are substantiated by hydrographs for the area. No specific investigation has been carried out into these apparent rises. However a possible explanation may be that the rises are in response to a reduction in flow or extraction from surrounding bores resulting in pressure gains. Whether these rises are directly in response to Cap and Pipe the Bore Scheme is at this stage unknown, further investigation is required to account for these apparent pressure rises.

Contouring of Head Differences map

The contouring of the head differences was carried out in GENAMAP GIS using an inverse distance methodology, whereby the value of the cell is calculated using a distance weighted value from known cell values. Cells of equal values or ranges are then combined. Grid cell size is 5 km and search radius of each cell is 50 km. Whilst this is a fairly unsophisticated contouring technique it provides an appreciation of regional trends.

It will become obvious from inspection of the map that in areas some bores have a substantial influence on that area, in proportion to the amount of data available for the area. These areas require careful consideration before conclusions can be drawn.

Where cells where unable to locate a known cell value, ie. the cell was greater than the search radius used from a known head value, the area was left blank.

Artesian Springs

The location of the Artesian mound springs is taken from the Pickard report of 1992. Pickard, J., 1992, "Artesian Springs in the Western Division of New South Wales" Graduate School of the Environment, Macquarie University.

The report summarises that some 45 sets of mound springs occur in the Western Division of New South Wales, 30 of which had in 1990/1991, permanent seeps of slight flows. Due to the difficulties attached with measuring the flows from springs, no flow data is available on the springs.

Springs are the surface expression of groundwater discharges which are believed to be structurally controlled, where groundwater can travel under pressure along faults to the surface resulting in deposition of salts via evaporation and the formation of mounds.

Potentiometric Surface Map Post 1986 (m AHD)

A potentiometric surface map of the main GAB aquifer in the Basin with general flow lines has been constructed using the following data set.

An extraction of pressure data available from the GDS for all bores was made which was then converted to metres head above a reference point. This head of water is calculated as the water column height as taken from the lower third of the main aquifer unit, or the midpoint of the lower screen within the main aquifer. A temperature correction was then applied to account for variations in density and hence head, allowing head values to be compared across the Basin. Digital Elevation Model (DEM) was used to obtain elevation data for each of the bores; the corrected head values were then converted to head (m AHD).

Points of equal head were then joined together creating equipotential lines; the potentiometric head map is used to represent the potential head at those places for the aquifer. Groundwater flow occurs because the potential energy head drives the water from areas of higher head to areas of lower head. Flow lines are used to represent likely flow paths and are constructed by drawing flow lines perpendicular to lines of equipotential head, from a higher head to a lower head. Where equipotential lines are closer together, indicates that the hydraulic gradient is steeper and that flow is likely to be greater, conversely further spaced equipotential lines indicate less hydraulic gradient driving the groundwater, thereby reducing flow in that direction.

This plan is suitable for providing general flow directions and expected hydraulic gradients. However the scale of the plan does not allow conclusions to be drawn for specific localities.

The data for the area north of Brewarrina suggests that flow in this area is quite complex with what would appear to be localised "sinks" and areas of low flow. It is currently unclear why there is such complexity in this area. It may be in response to Basin structure, as the area traverses the Surat and Eromanga Basins, referred to as the Cunnamulla Shelf, a rise in basement depth. Further investigation is required to explain this area. The flowlines also suggest that flow is draining towards the area between Walgett and Brewarrina. This would suggest that he area is a discharge zone, however Pickard has recorded few springs in the area. Springs would be expected as an indication of a discharge zone. The accompanying flow map and head differences map do not immediately suggest an explanation for the flow lines. Further work is required on where the flowlines are directed and or why this plan suggests the area is behaving as a "sink" before any conclusions can be drawn.

NSW GAB Flow Boundaries

The flow boundaries for this map have been taken from work carried out by other researchers in the Department over the years. The basic approach taken is to plot the location of bores for that year, or period, of known flowing and non flowing bores, from which an interpreted boundary can be drawn. This boundary between flowing and non-flowing bores is a generalisation and assumes that all bores intercept the full thickness of the main aquifer and does not consider topographical effects. The NSW Great Artesian Basin Flow Boundaries map provides the following statistics.

YEAR	AREA hectares	Difference between years	Approximate rate of decline ha/yr.
1920	11,668,568		
1954	9,288,769	34	70,000
1995	7,469,388	41	44,000

Note 100 ha = 1 km^2

These numbers are approximates and should be used with caution, however they do suggest that the area of land in which the bores drilled into the basin is reducing at a rate less than what was occurring in the early part of the century.

Post 1986 Latest Flow

The GDS was interrogated to provide all flow records for bores. The data was filtered to provide the latest flow records available post 1986. This data was then grouped into four ranges corresponding in general with the 25, 50, and 75 percentile ranges to assist in the presentation of the data. The flow ranges are <1L/s, 1-3L/s, 3-7L/s, and >7L/s with a maximum flow rate in the NSW part of the Basin of over 40L/s.

The data was then contoured using the four ranges to assist with data presentation. In the initial draft a 5 km grid with a search criteria of 50 km was used to give general flow rate distribution over the Basin. The search criteria was reduced to 20 km to reduce the interpolation between cells and minimise inappropriate assumptions being made about specific areas and expected flow rates.

It appears that in general flow is related to Basin structure, greater flow is found where the Basin is deepest; conversely shallow depth to aquifer would suggest lower flows. Further work on aquifer thickness would assess how important this component is in conjunction with aquifer depth in providing yields.

Hydrographs

The Hydrograph Locations plan looks at bores with a long monitoring record, which typify a particular area. Initially the bores where selected based on those bores which form part of the current annual monitoring network, some 37 bores have been chosen. Further work is required to assess which bores and areas require more hydrograph information.

The hydrographs assume that the point at which the measurement is made is at ground level. The convention in groundwater for water level measurements is that a negative value of head indicates an above (measurement point)/ground reading, whilst a positive value of head indicates below ground.

Appendix B: Hydrographs

Arranged in numerical order. Refer to Figure 7 for locations

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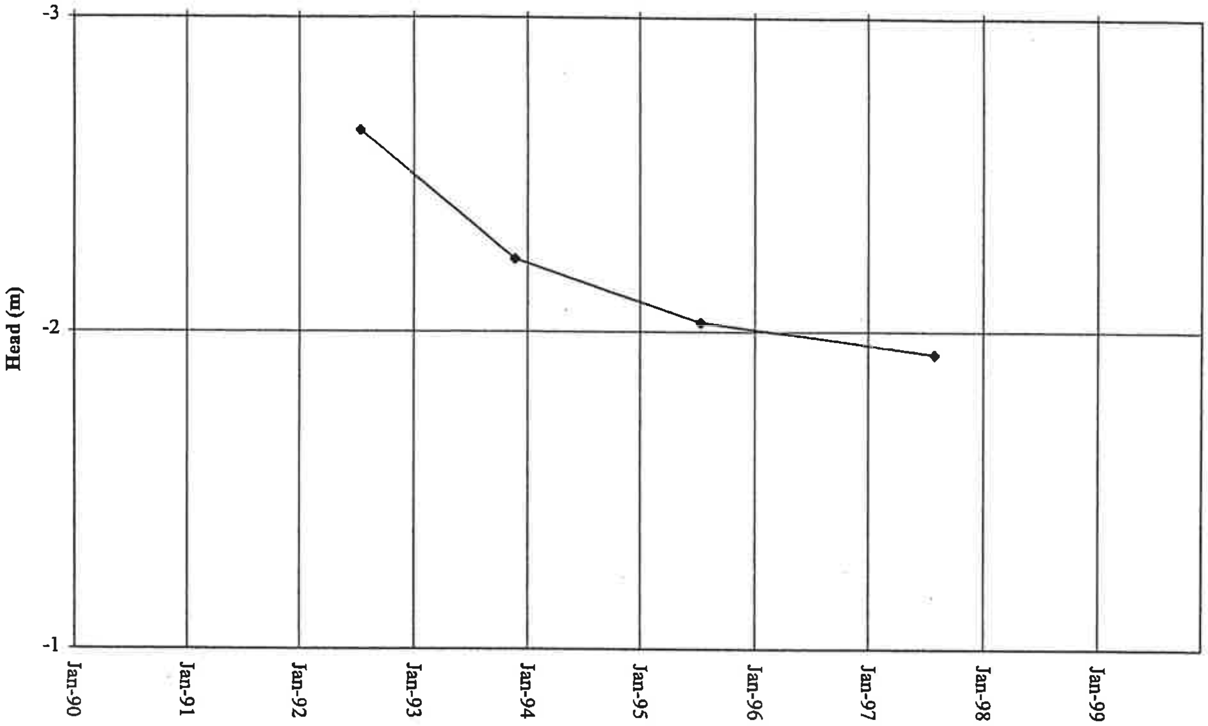

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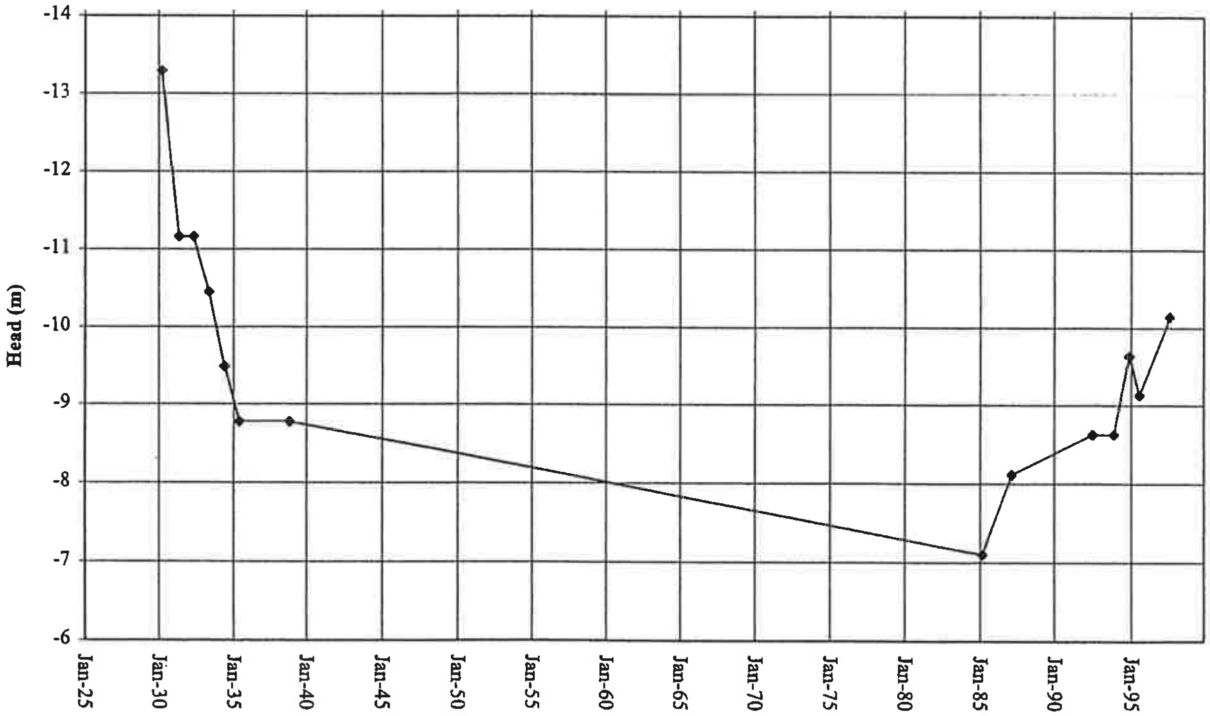

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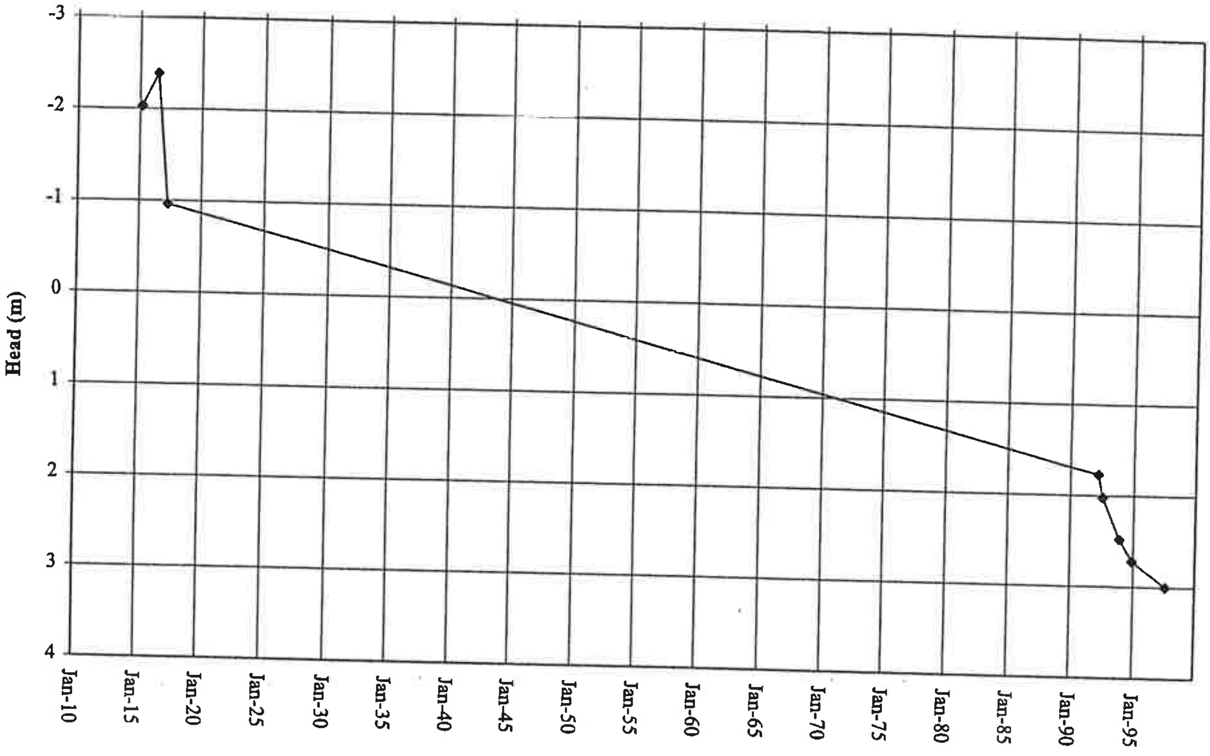
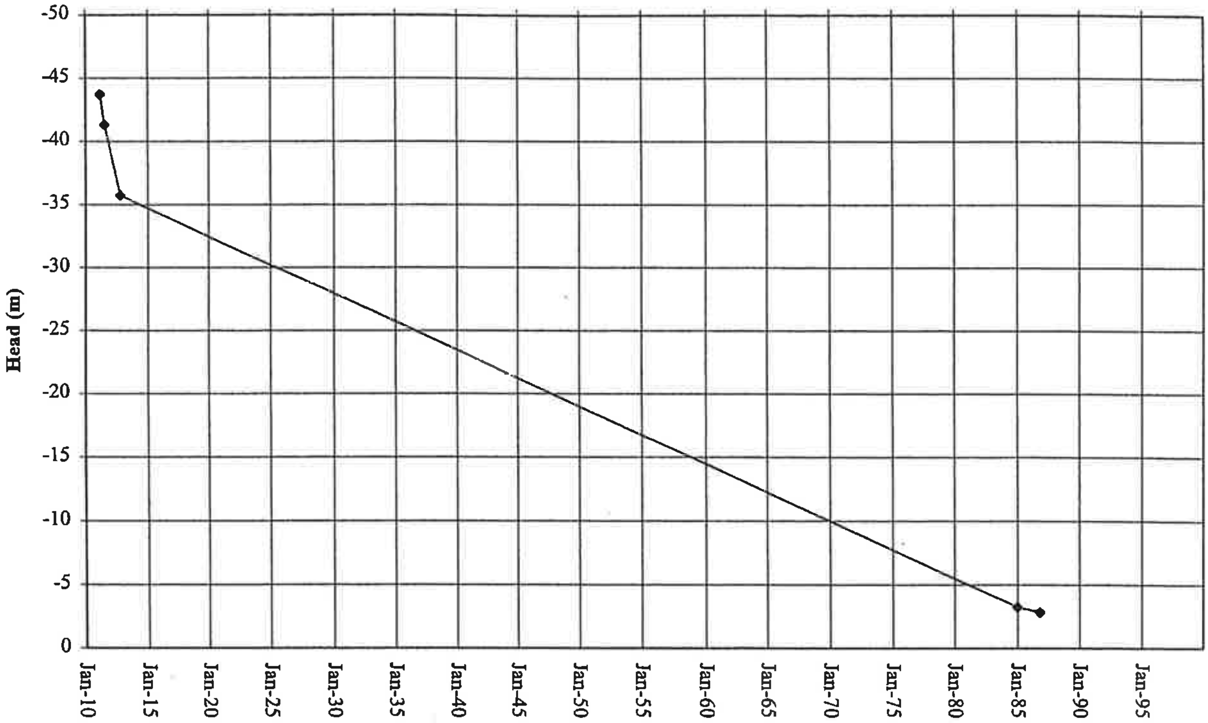


GW004024 BOOMI

GW004034 Bryanungra



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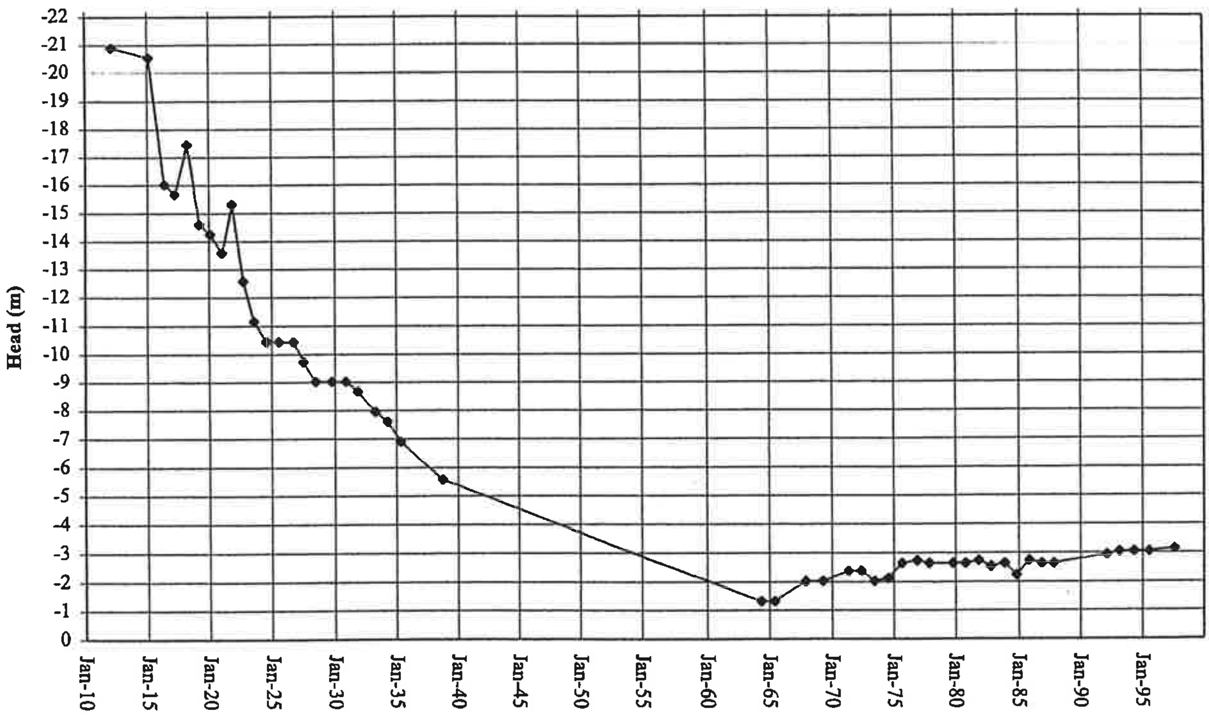

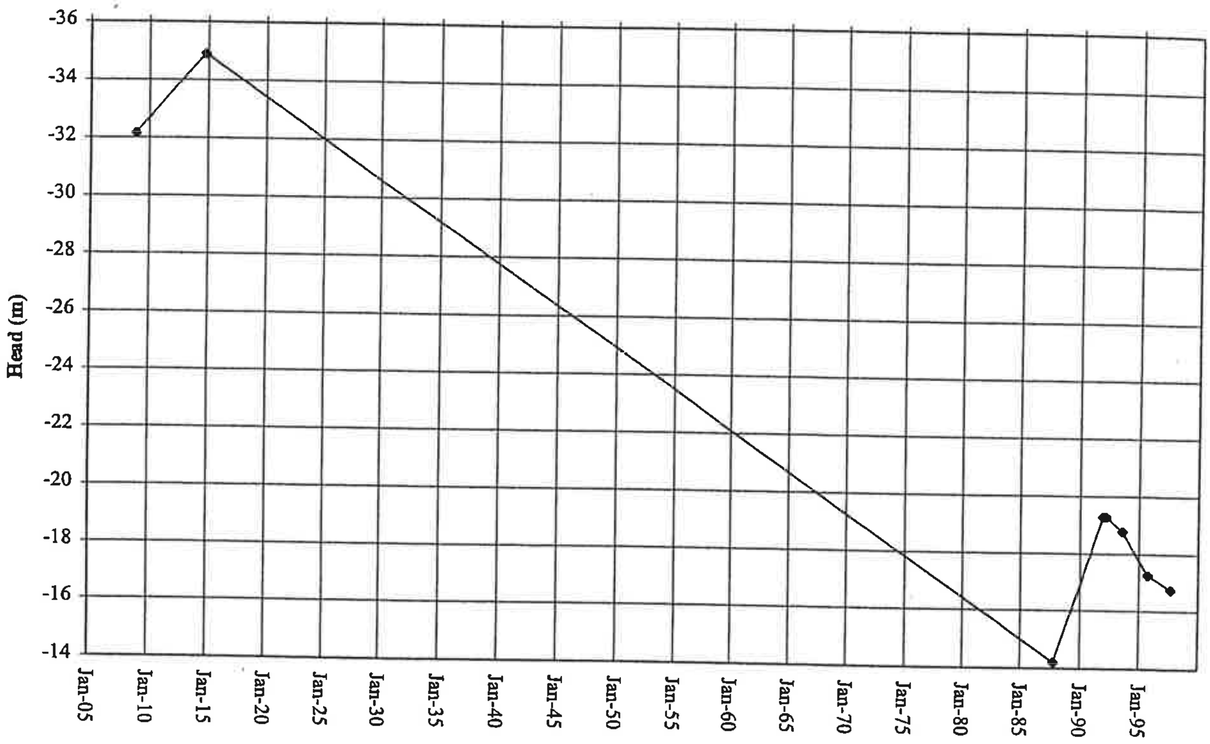

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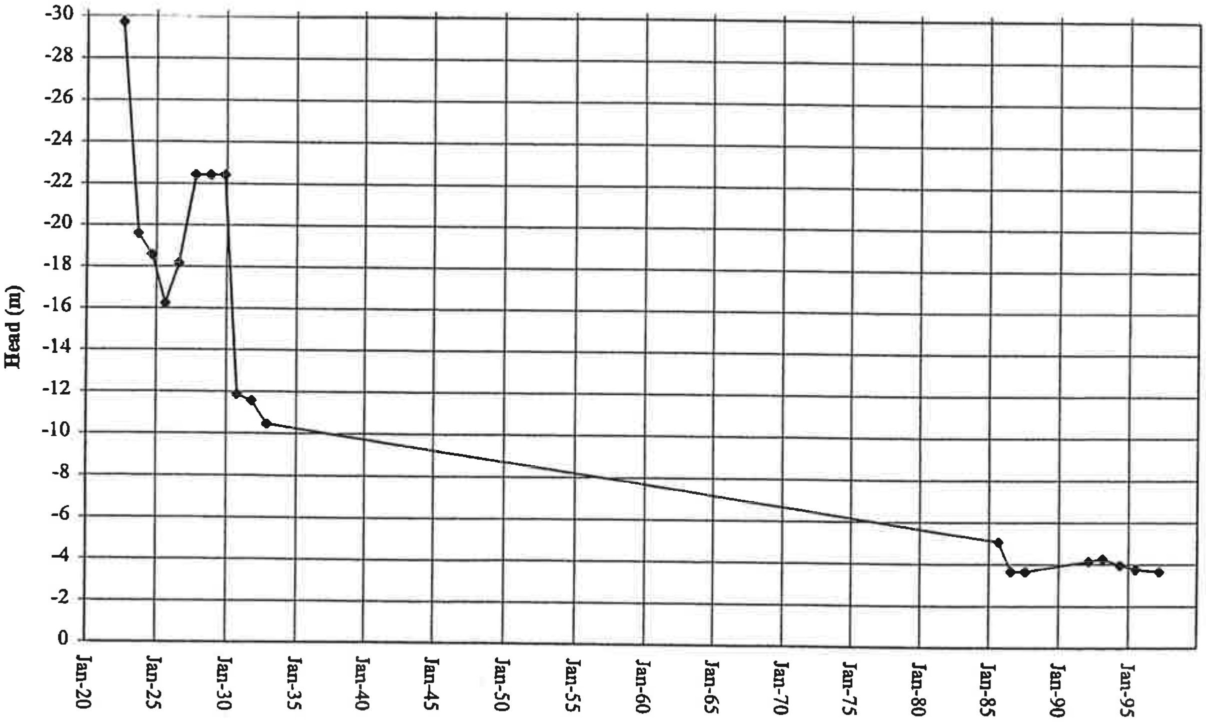

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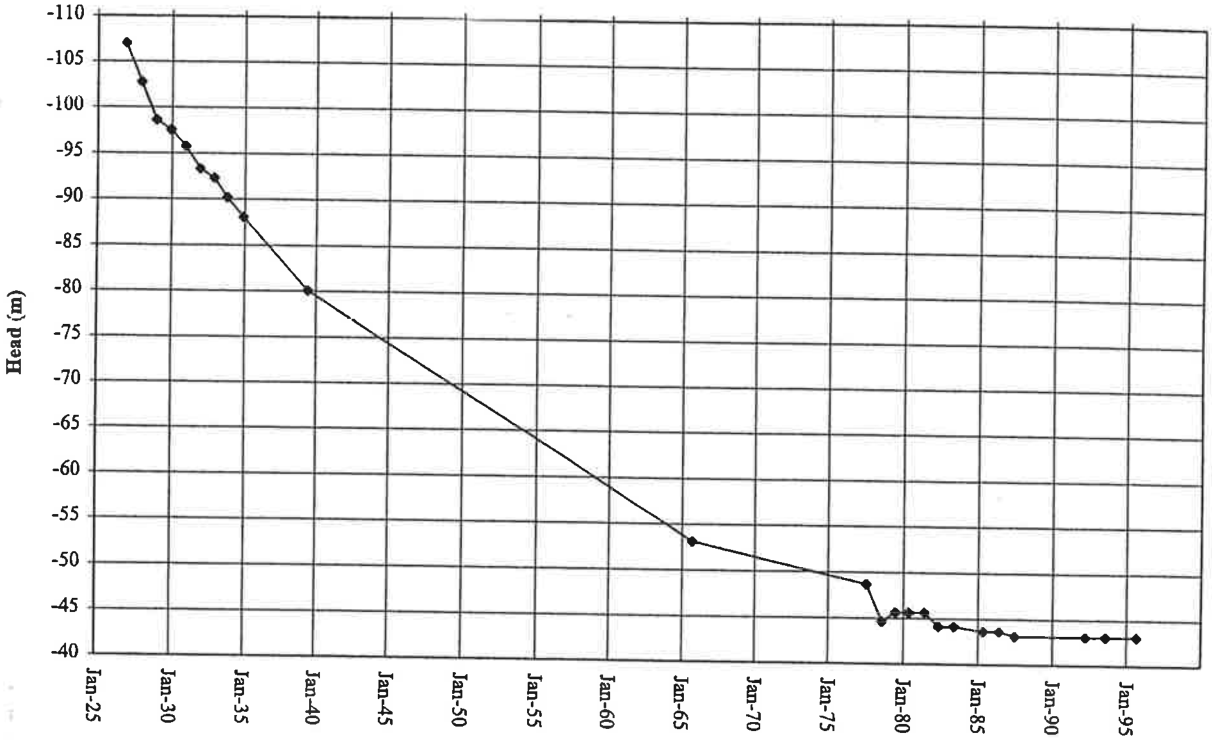
GW004085 ANGELDOOL No.2



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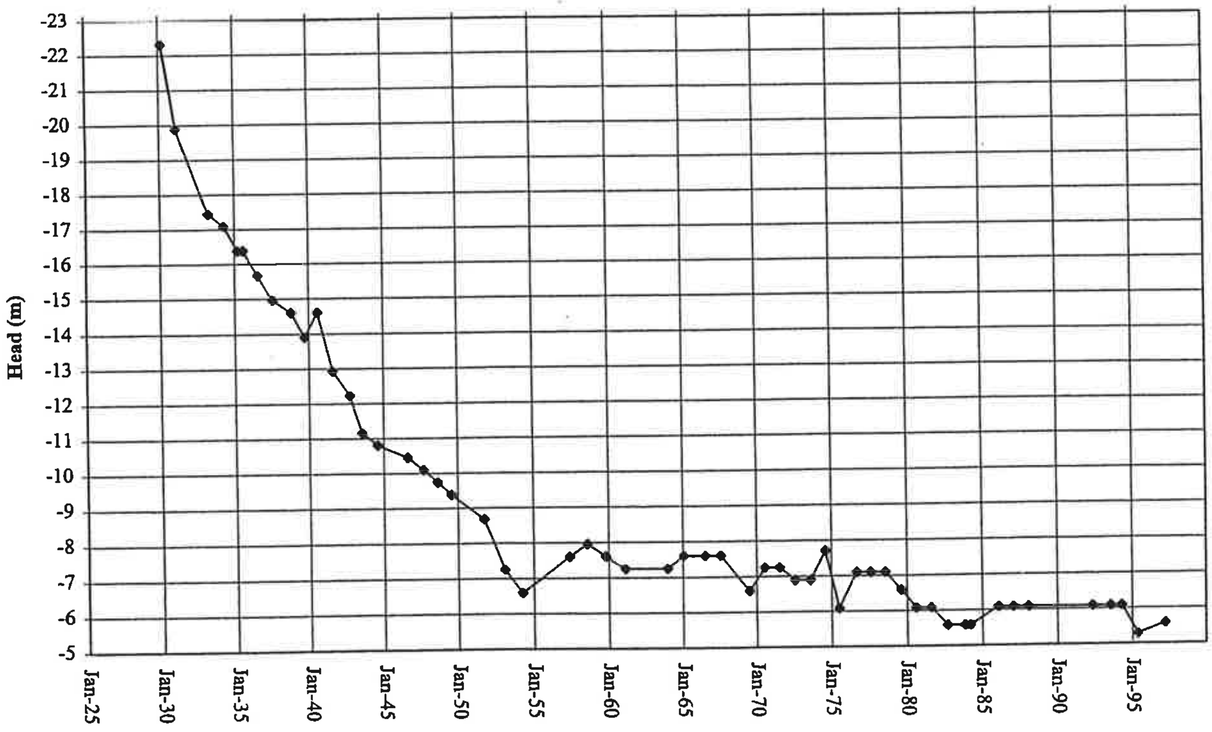

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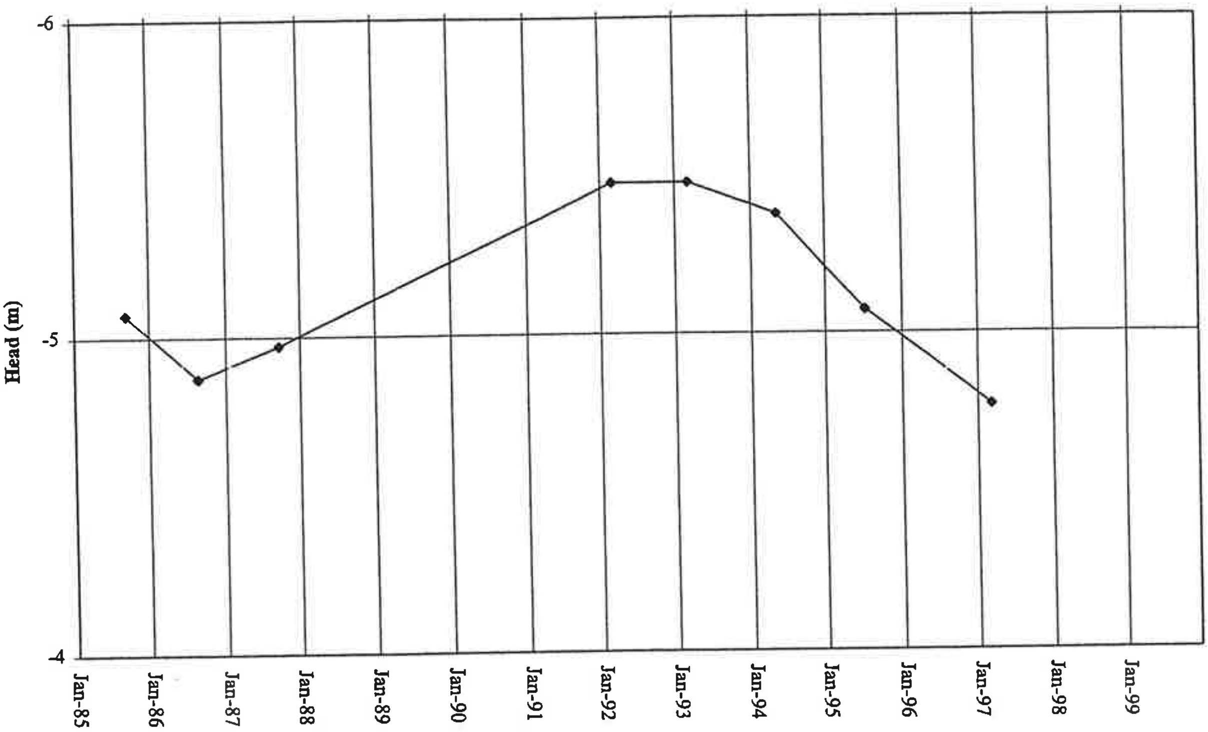

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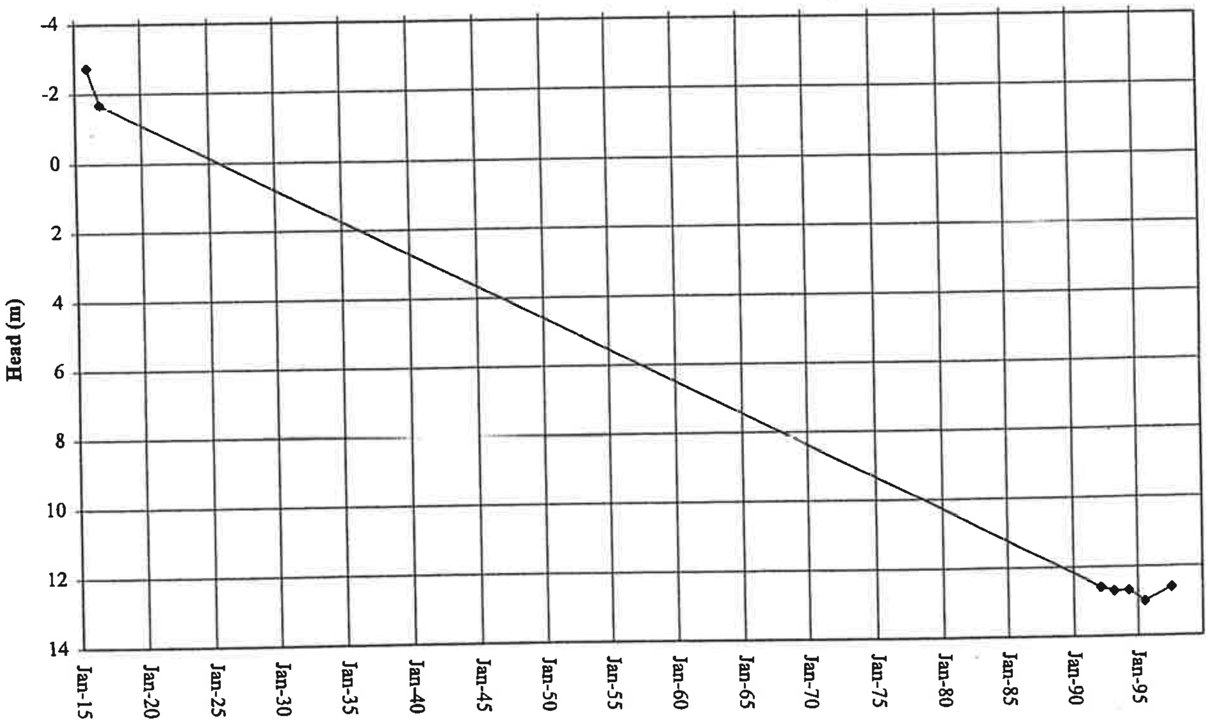

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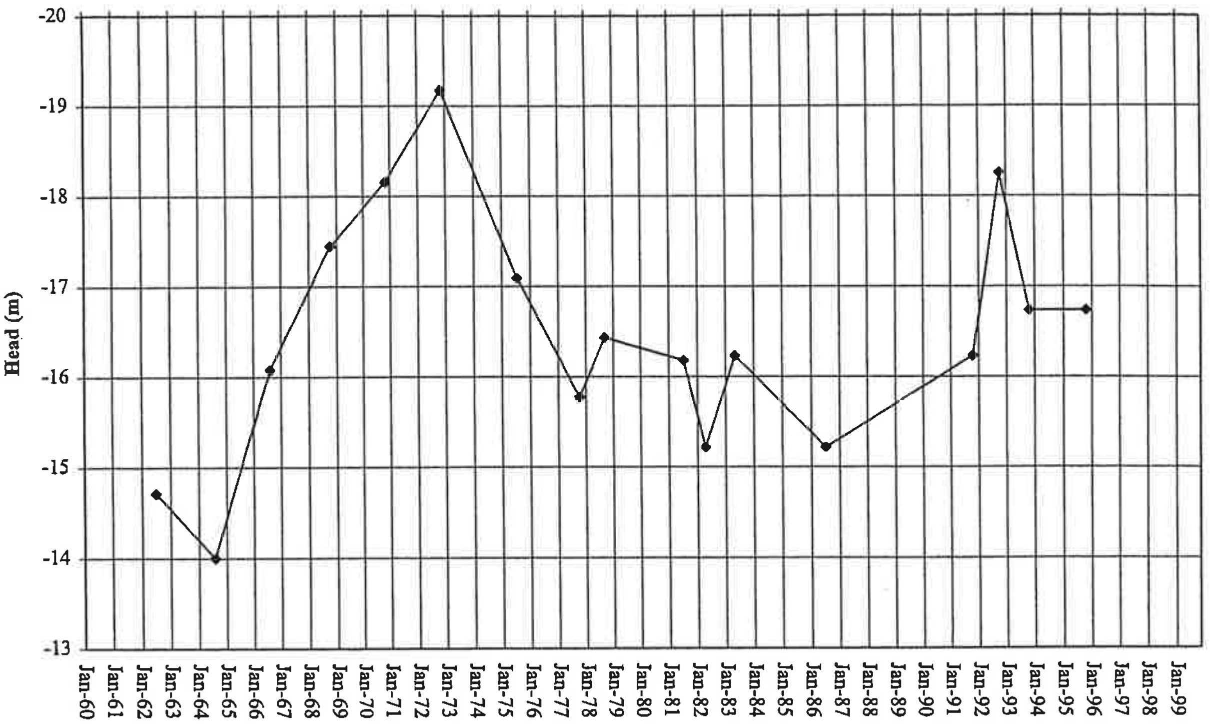

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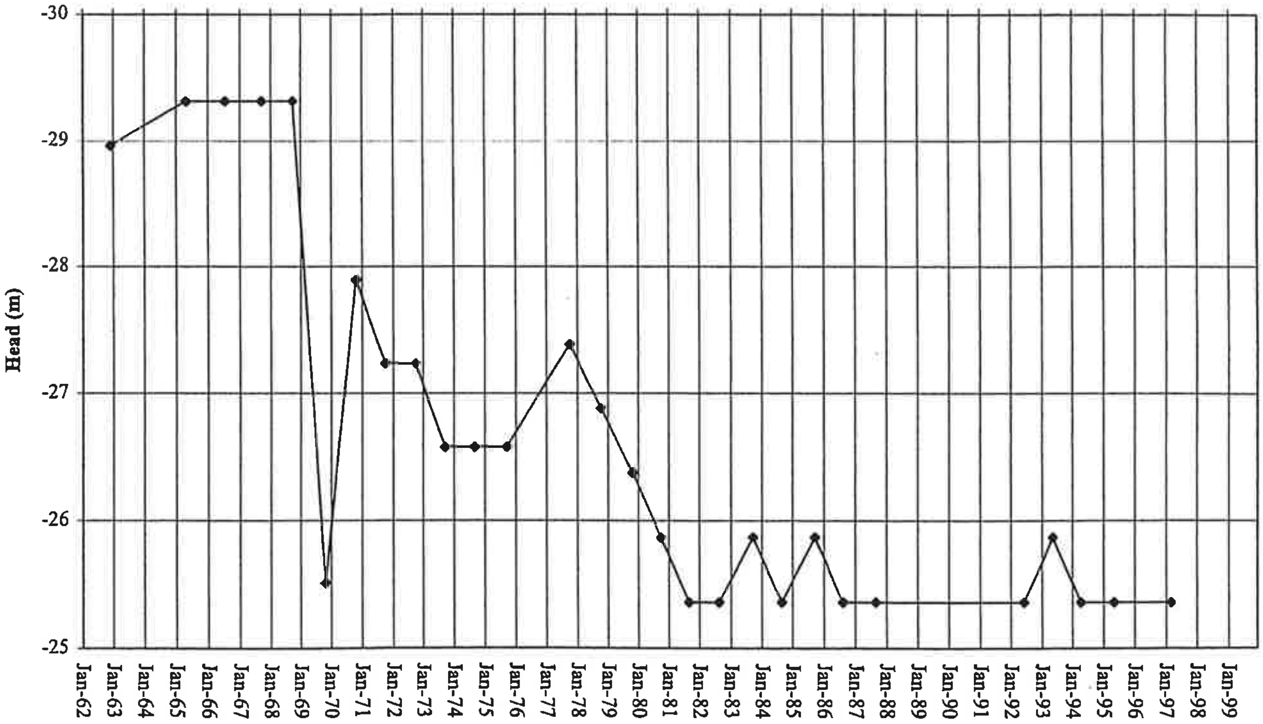

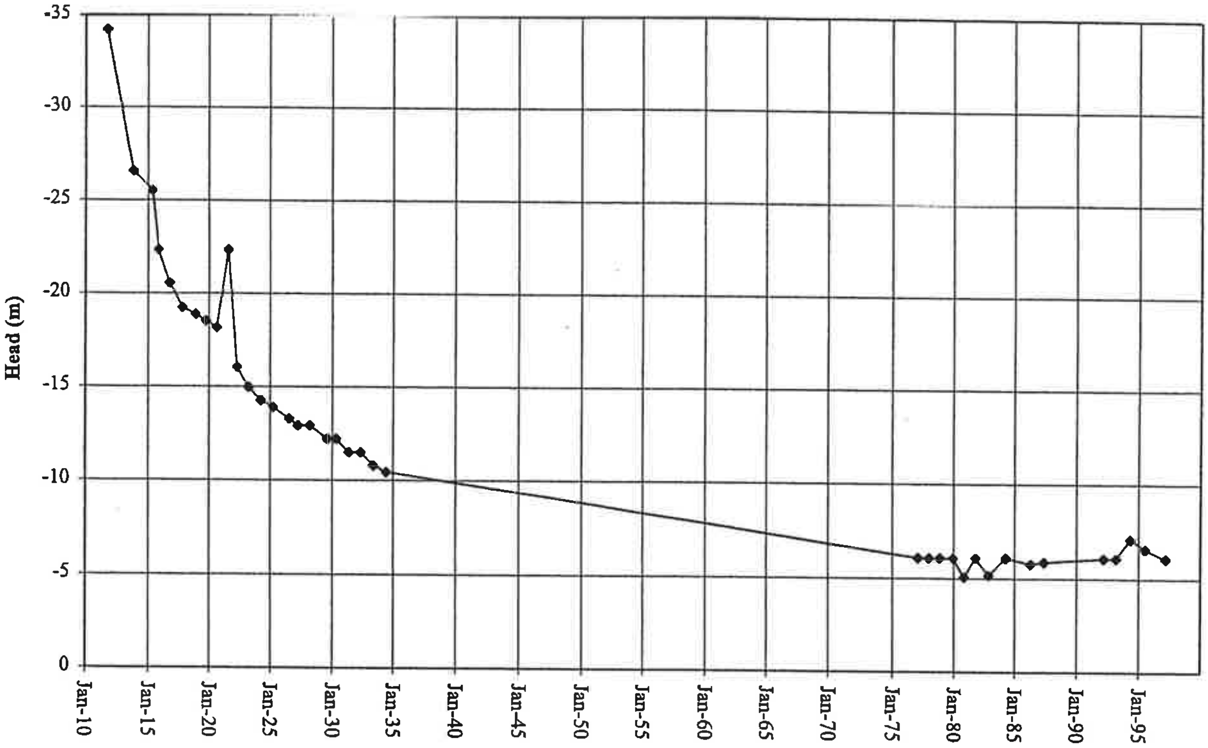

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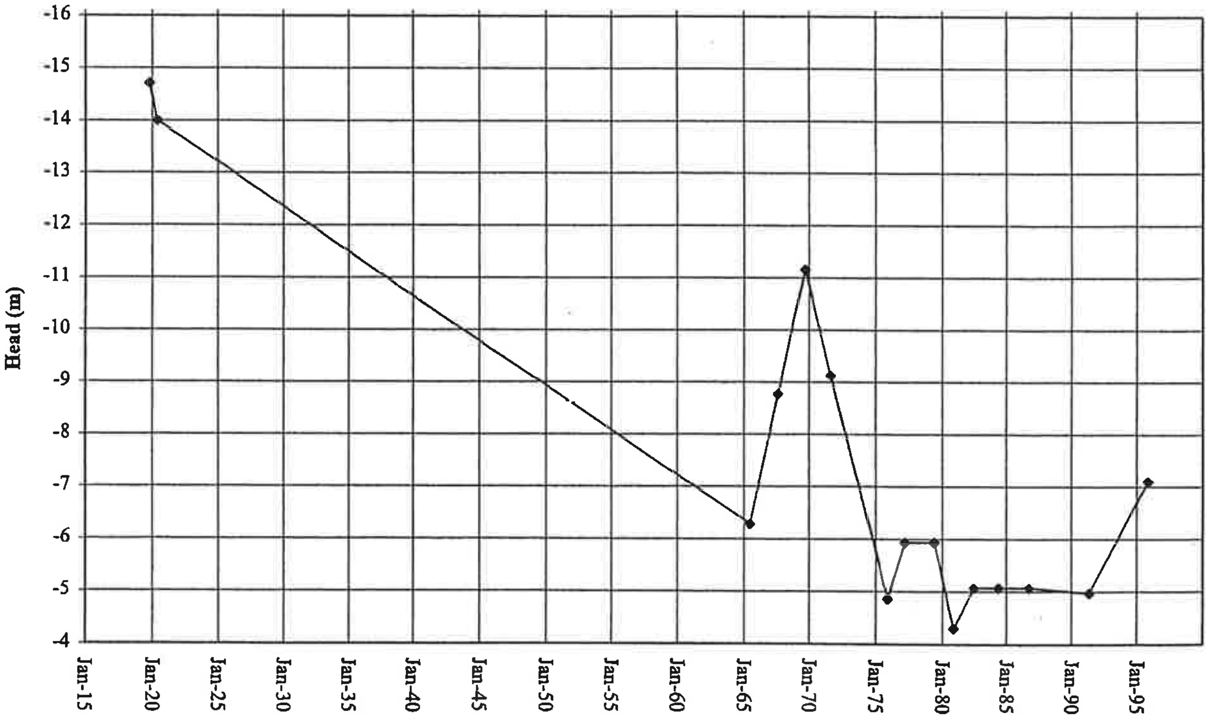
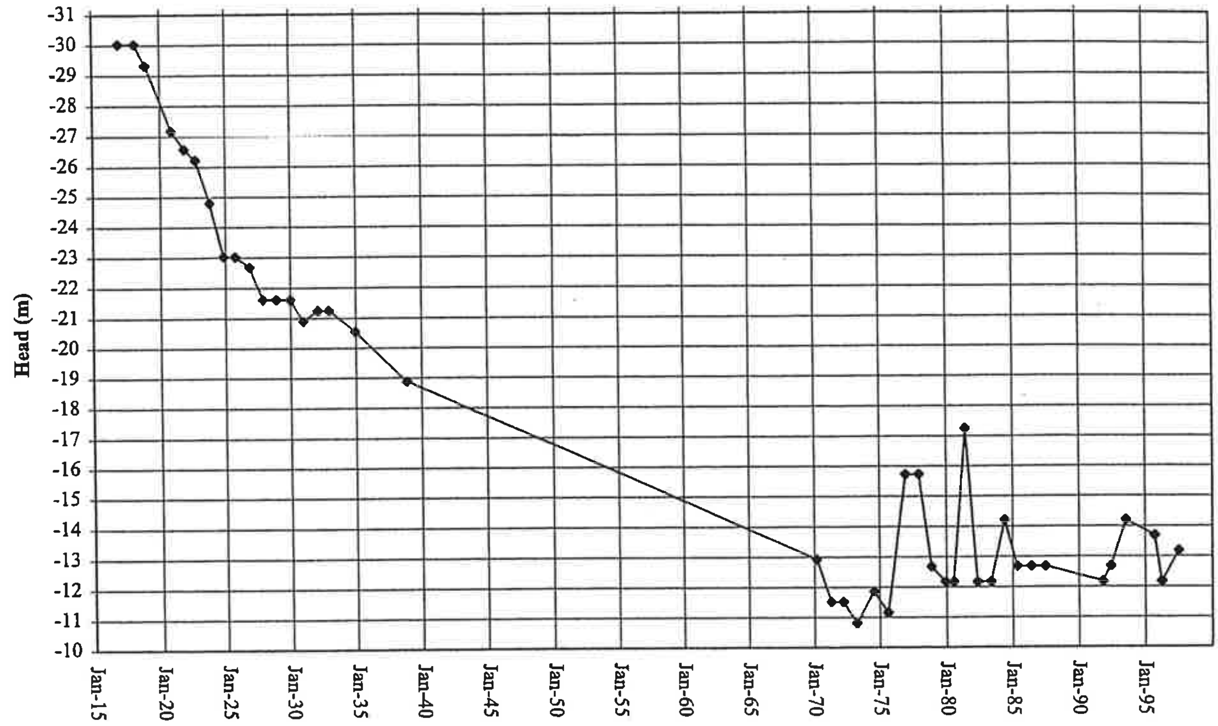


GW004289
KILLOWEN

GW004362 MORENDAH



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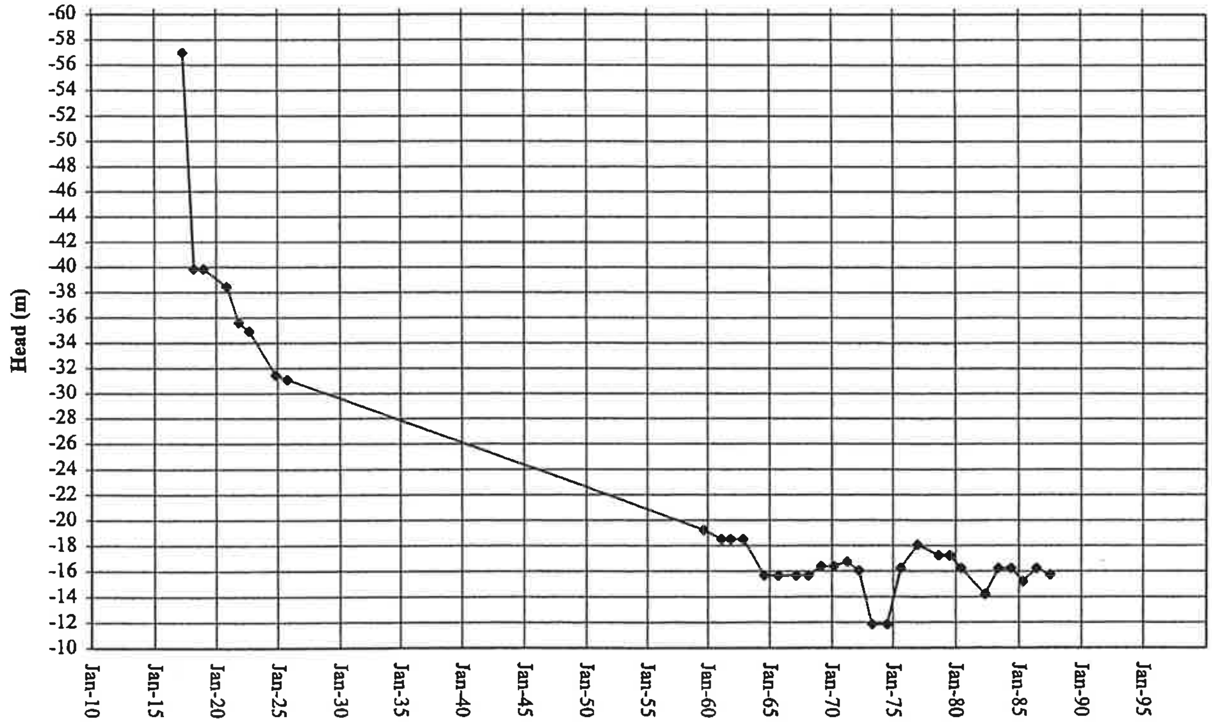

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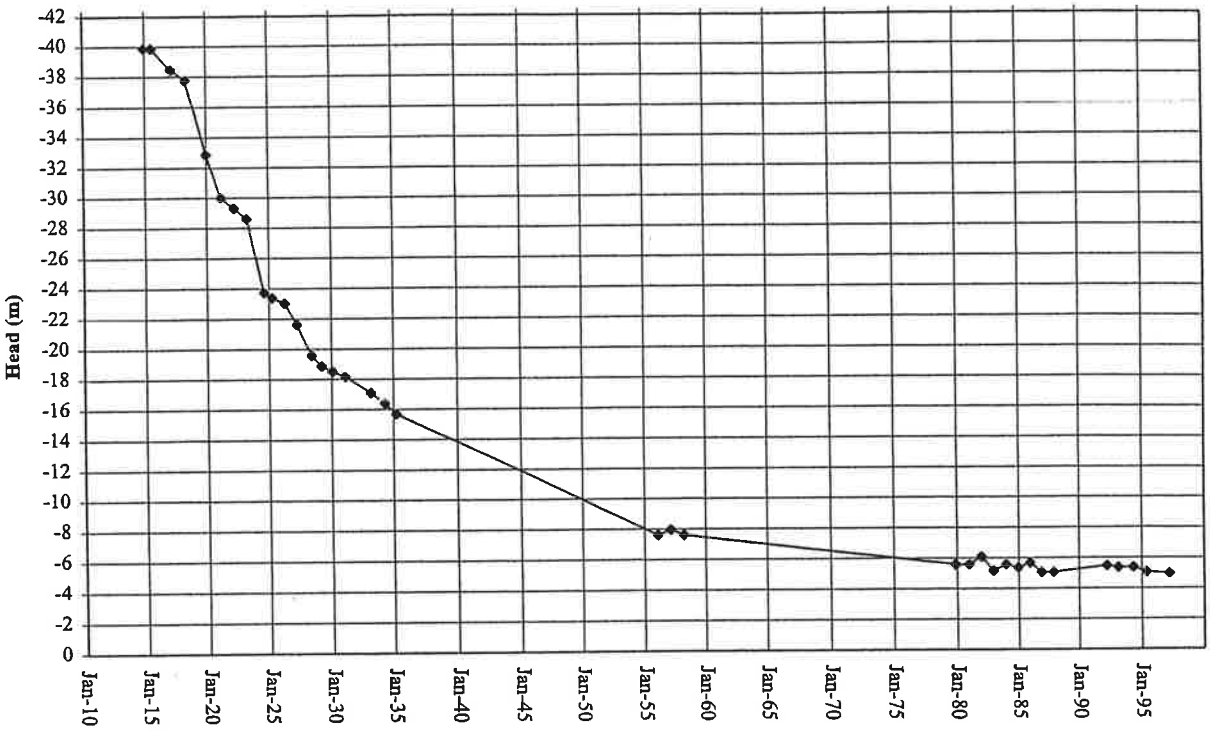

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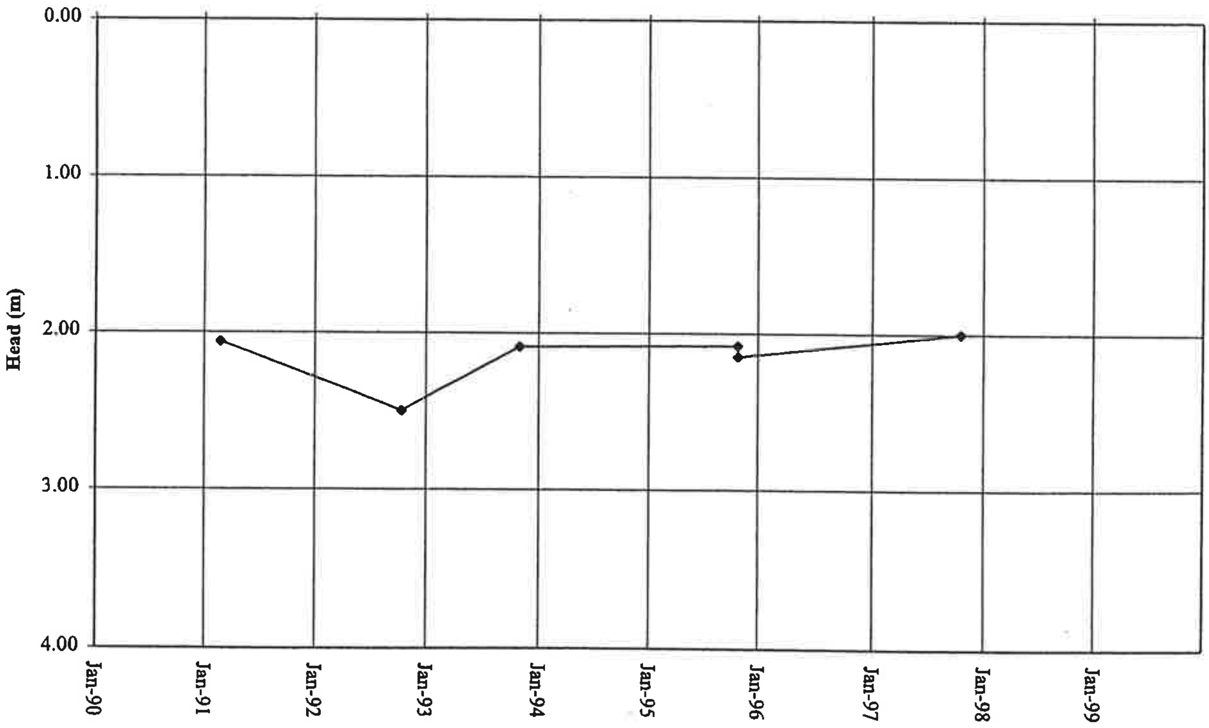

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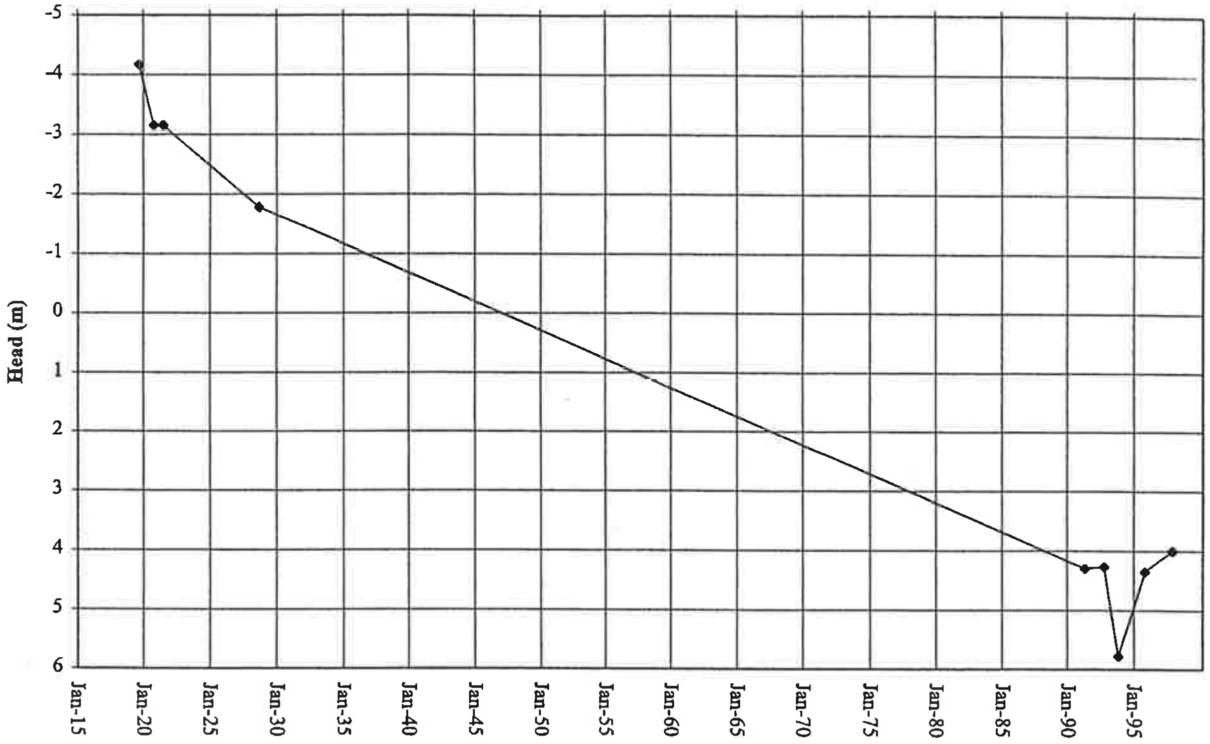

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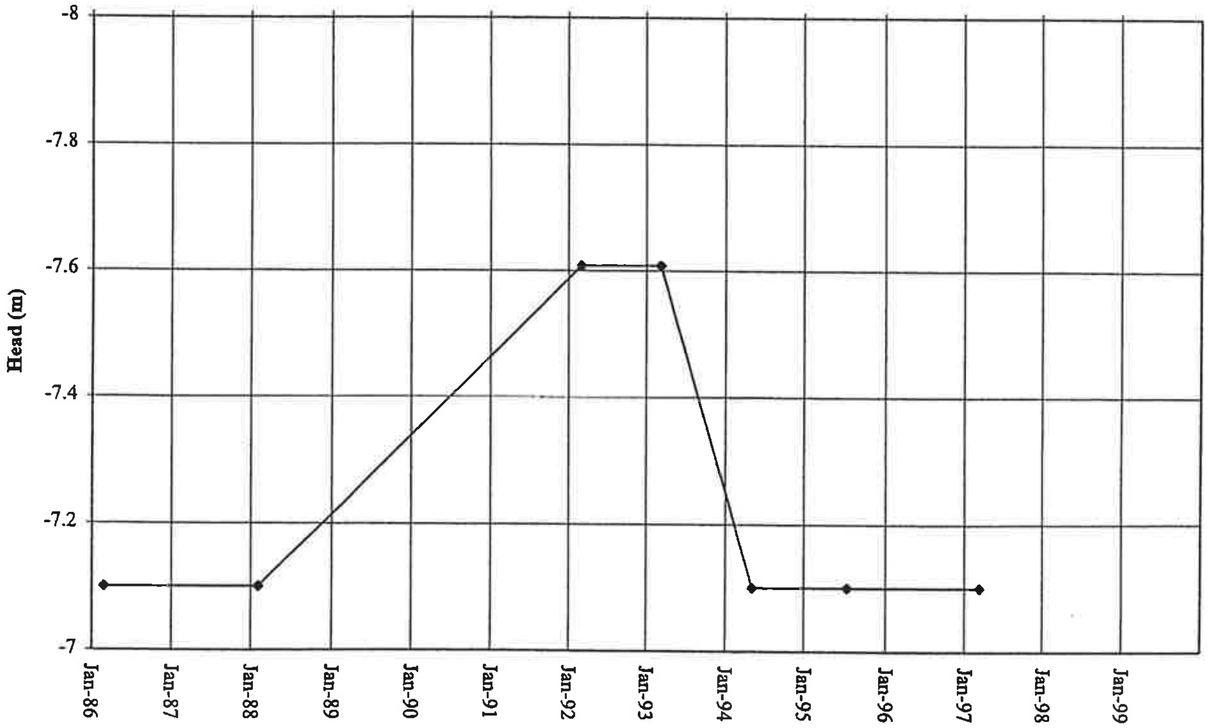

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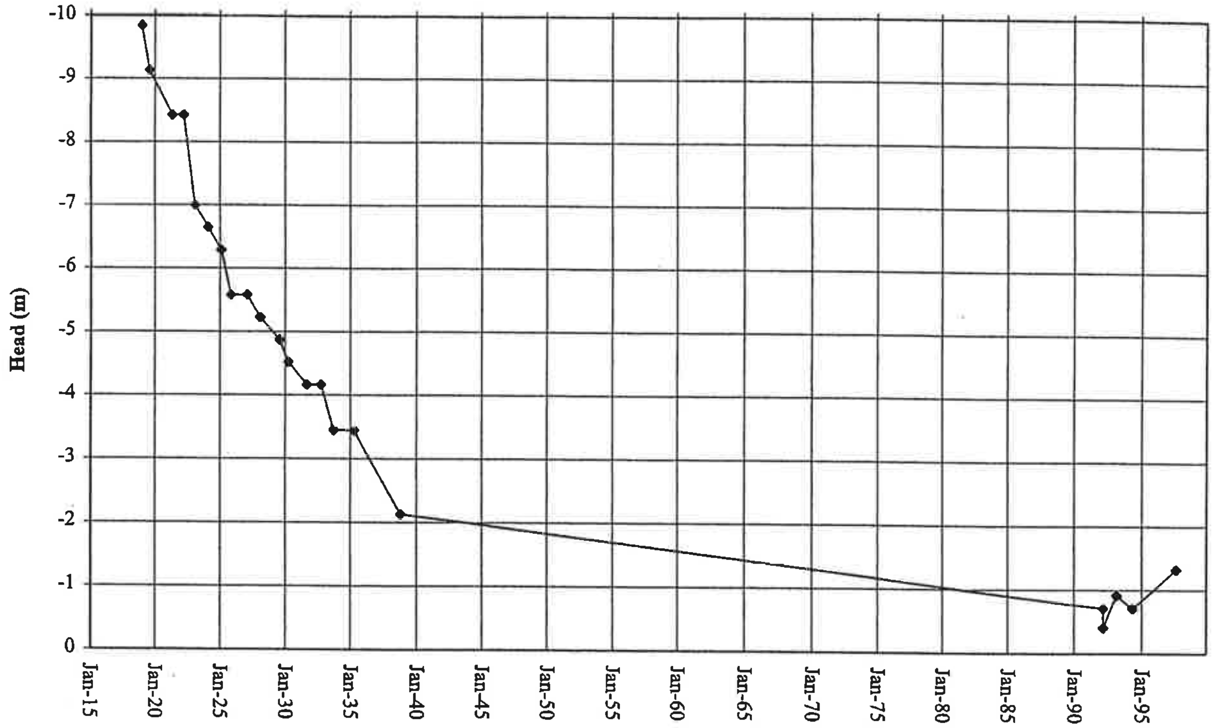

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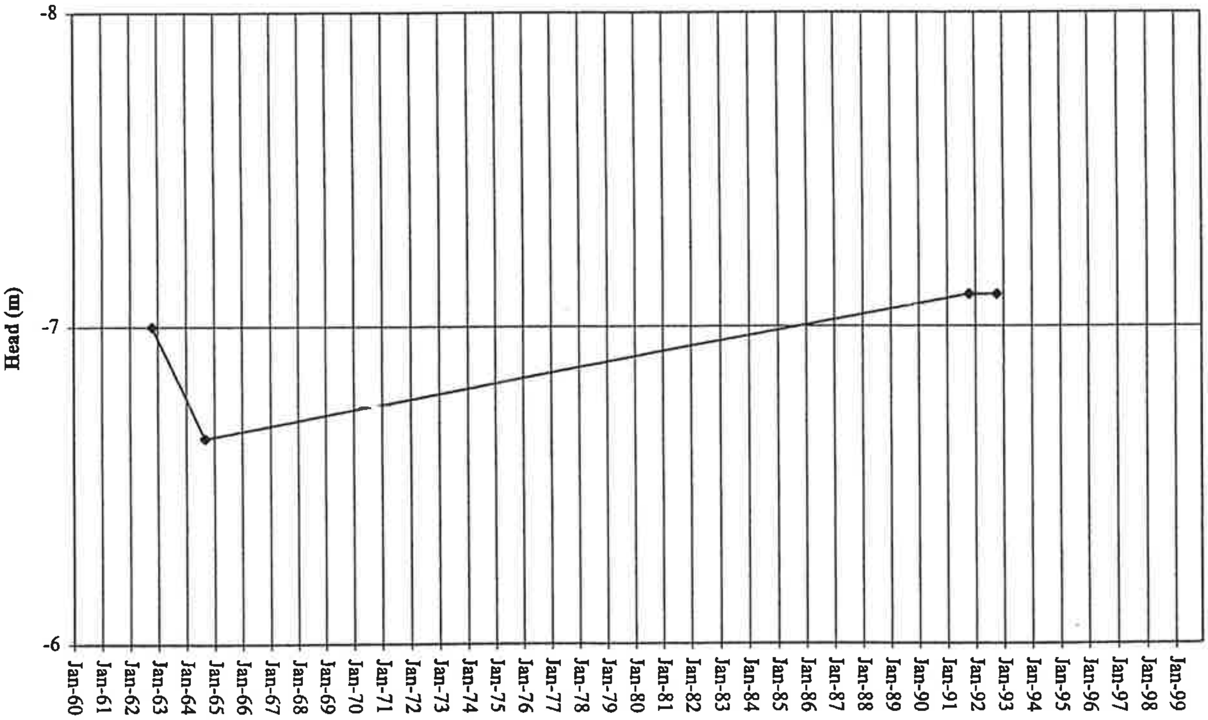

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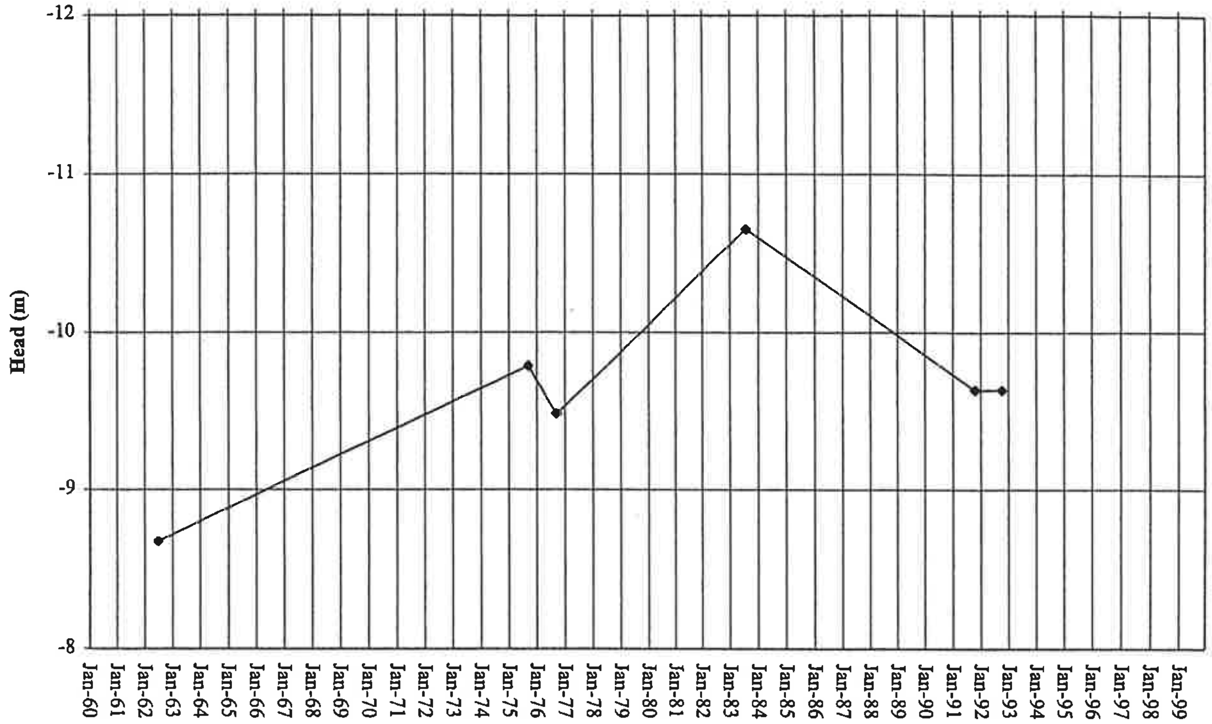

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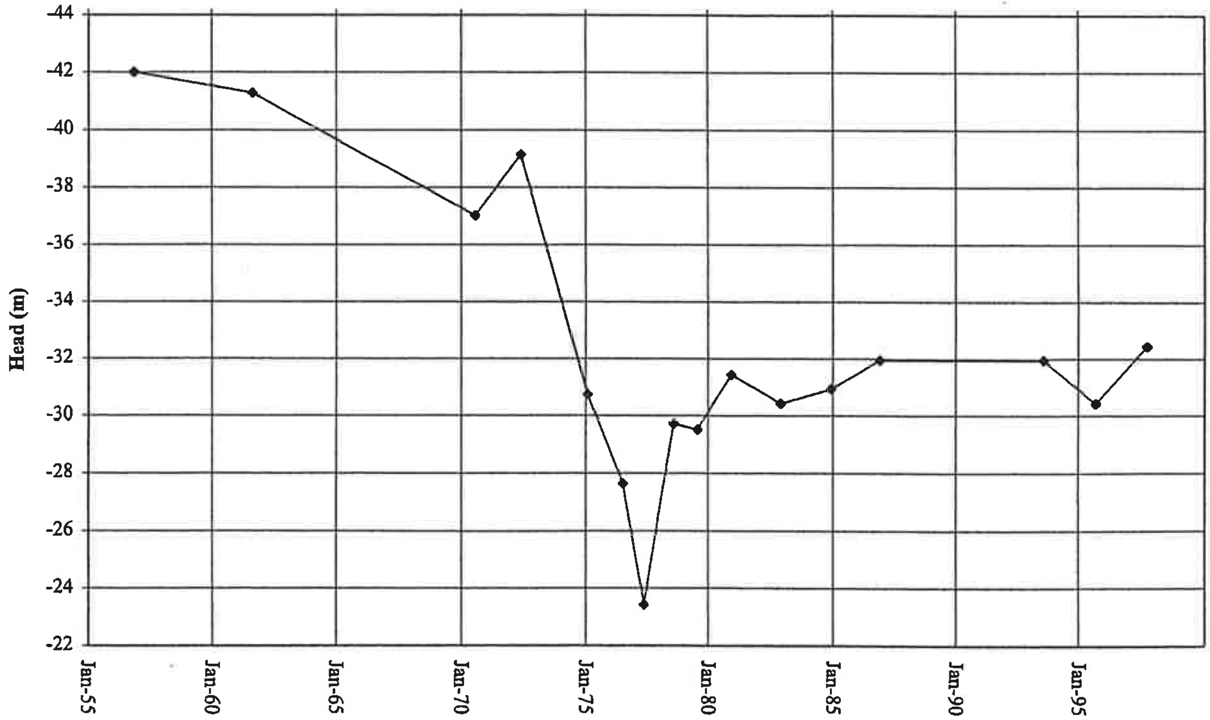

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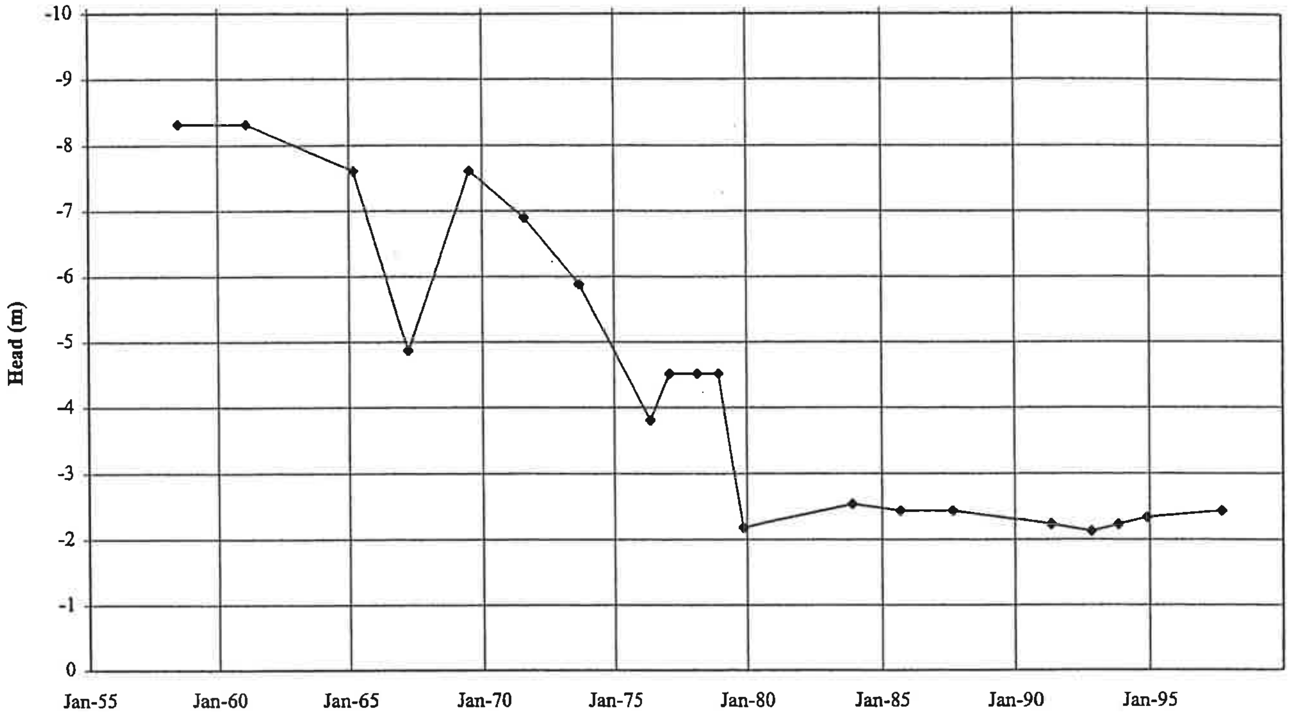

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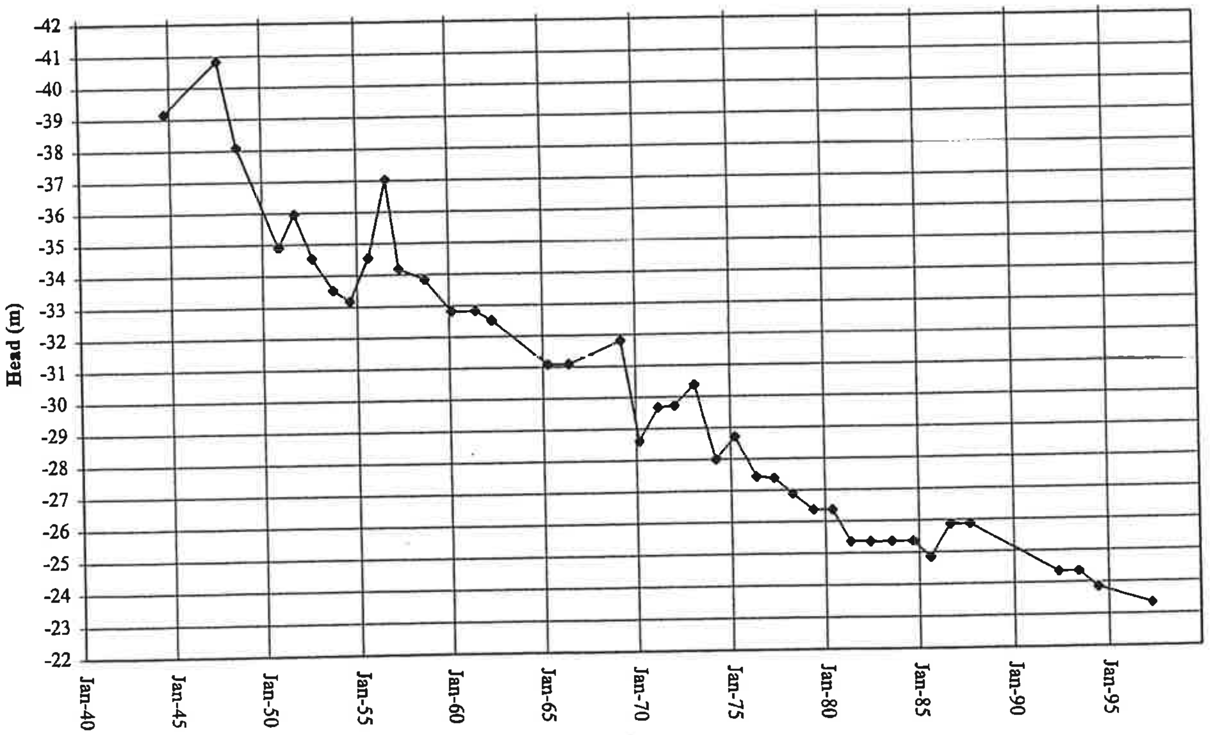

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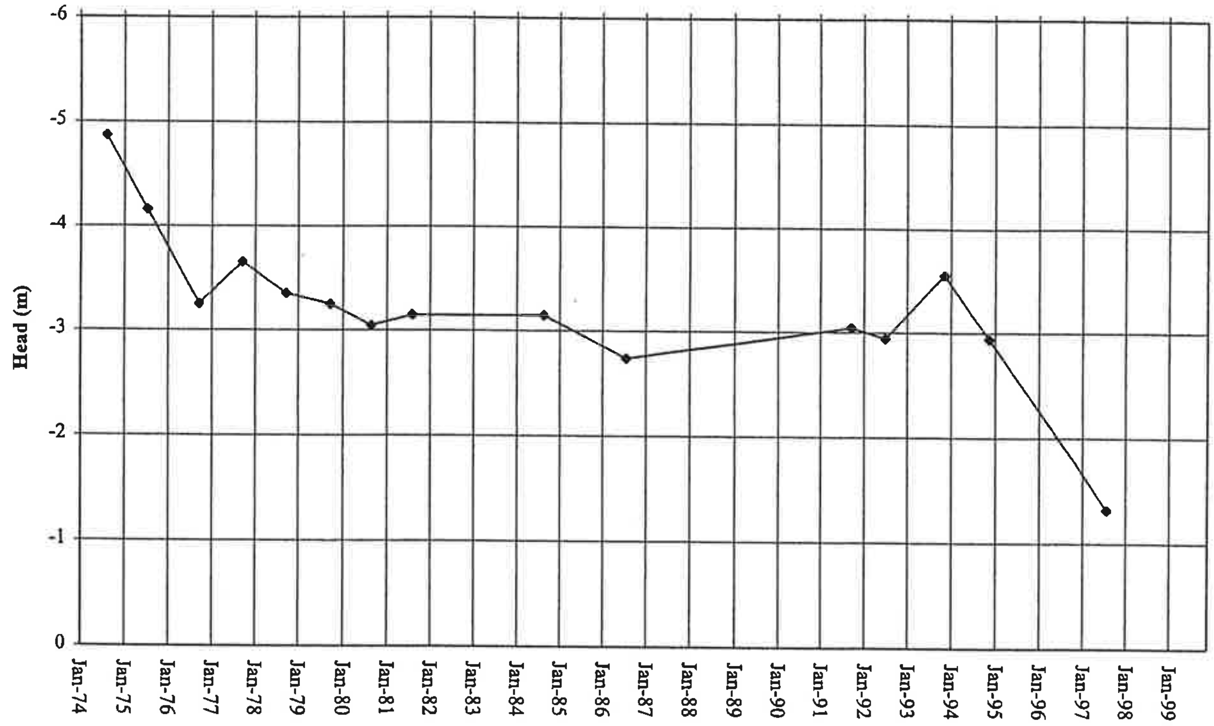

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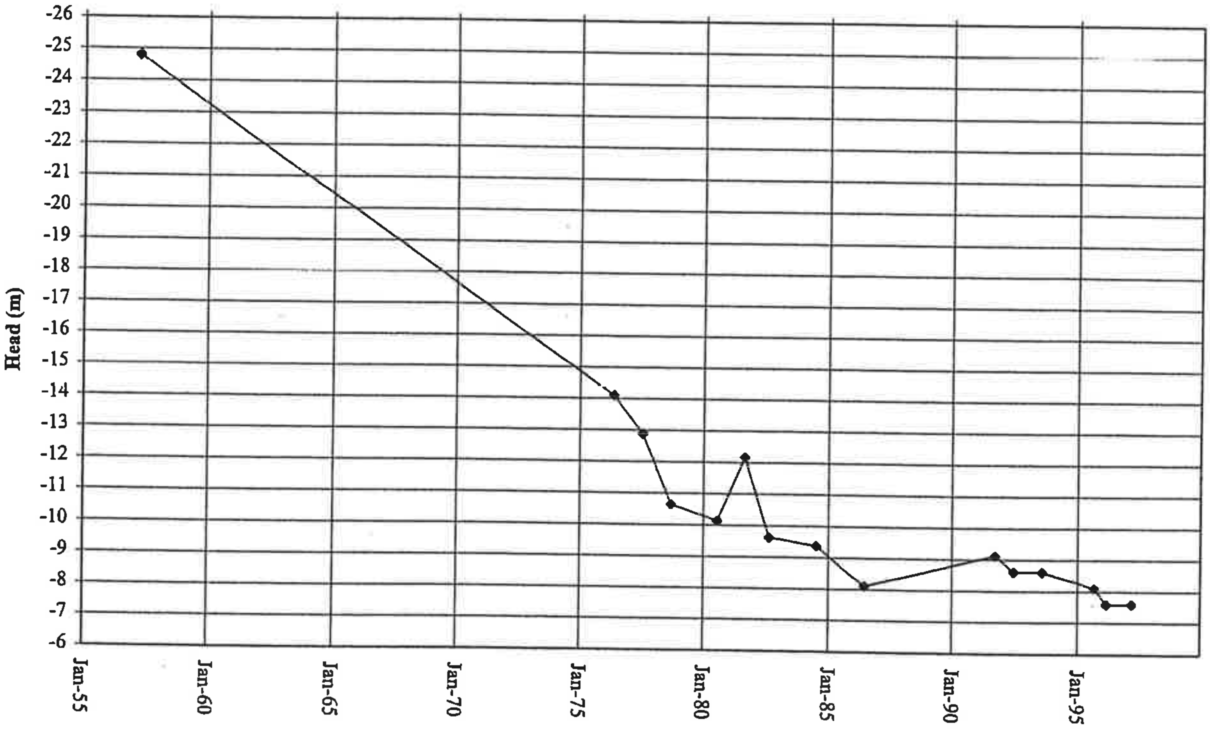

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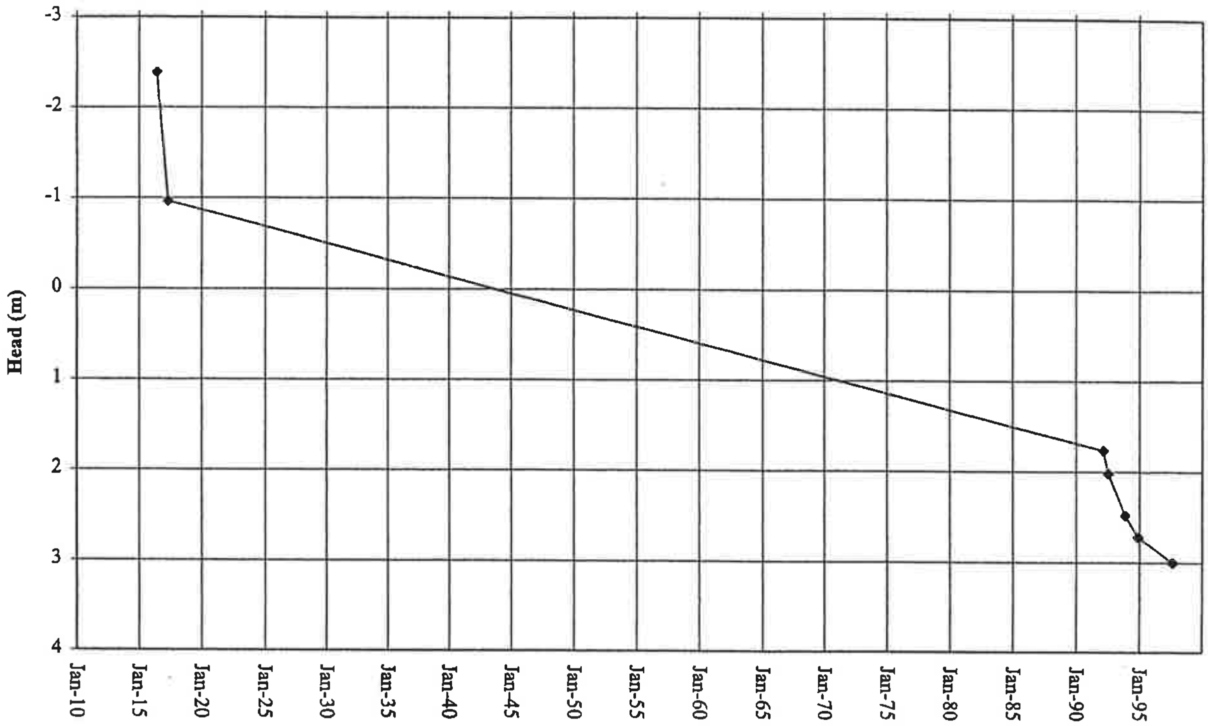

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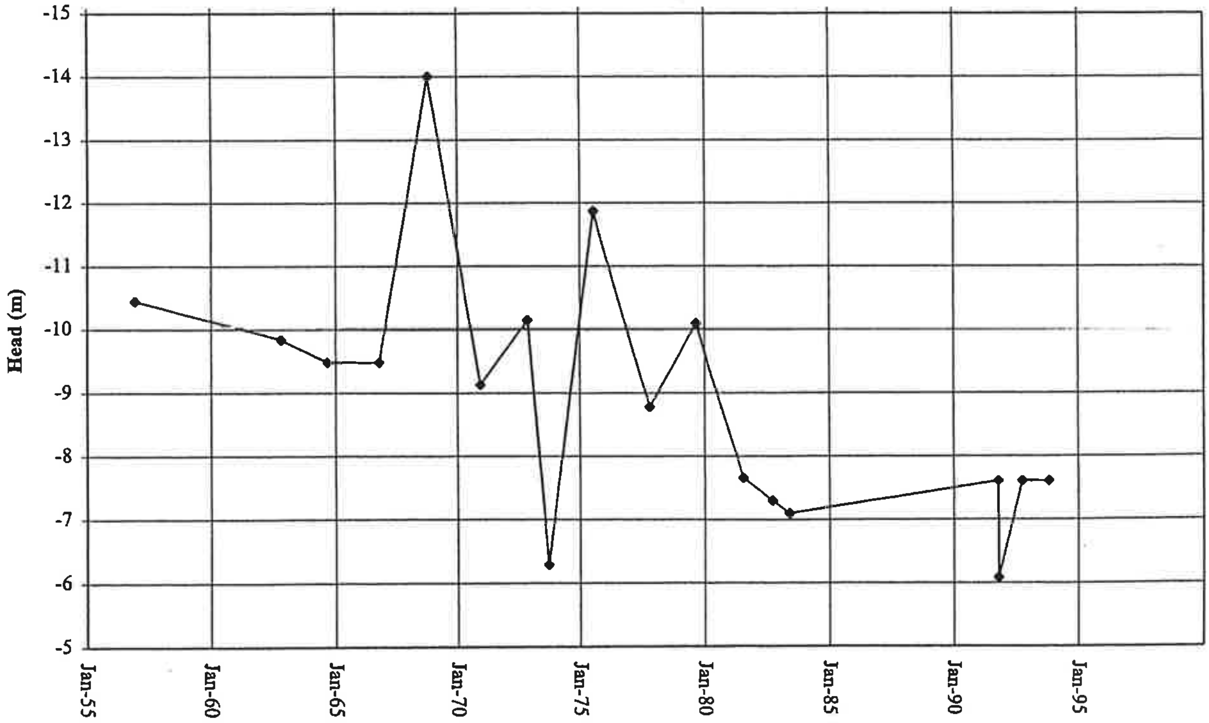

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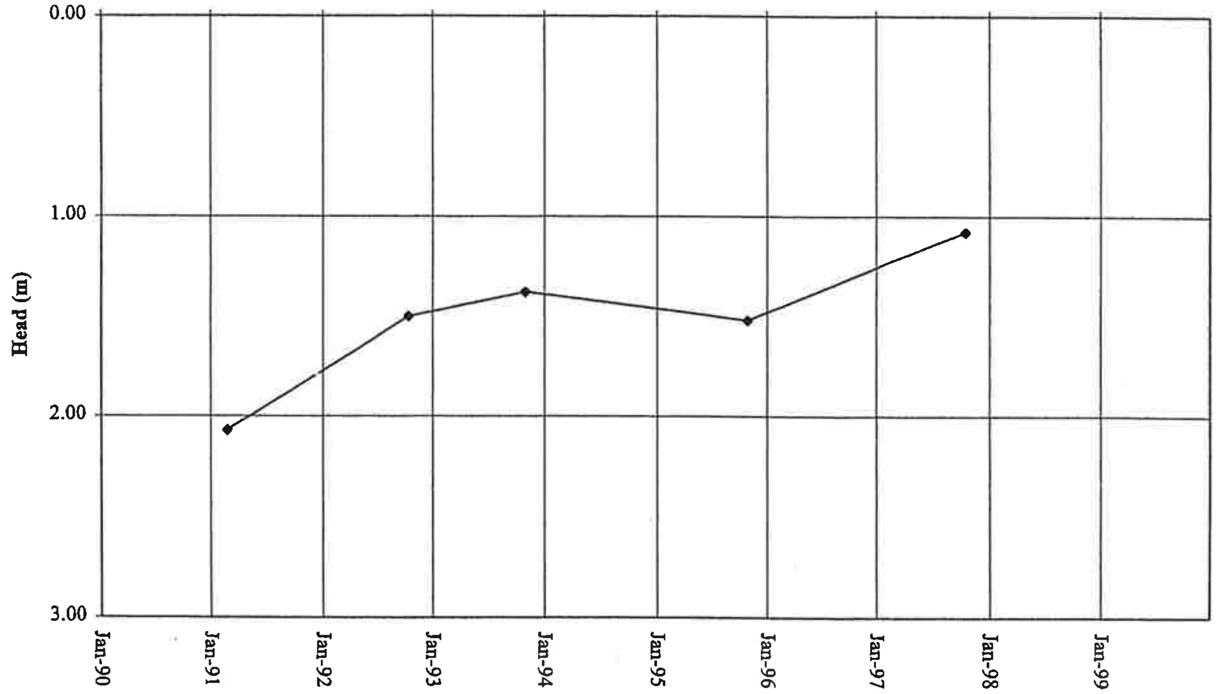

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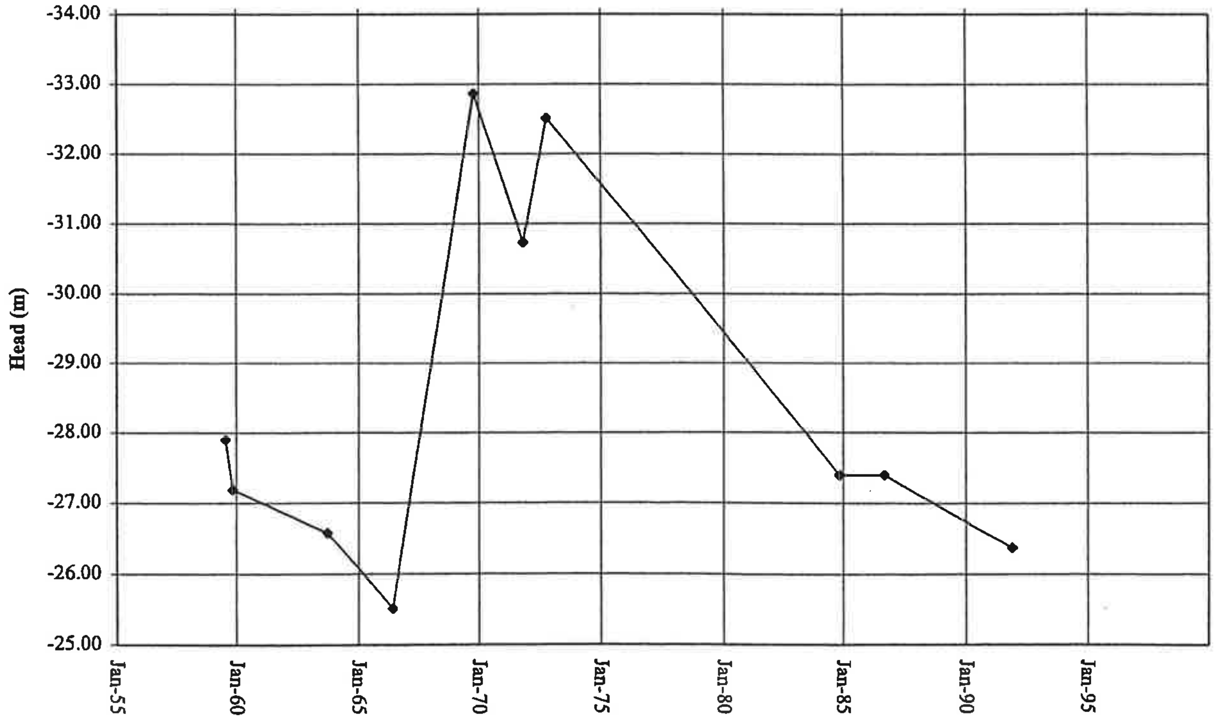

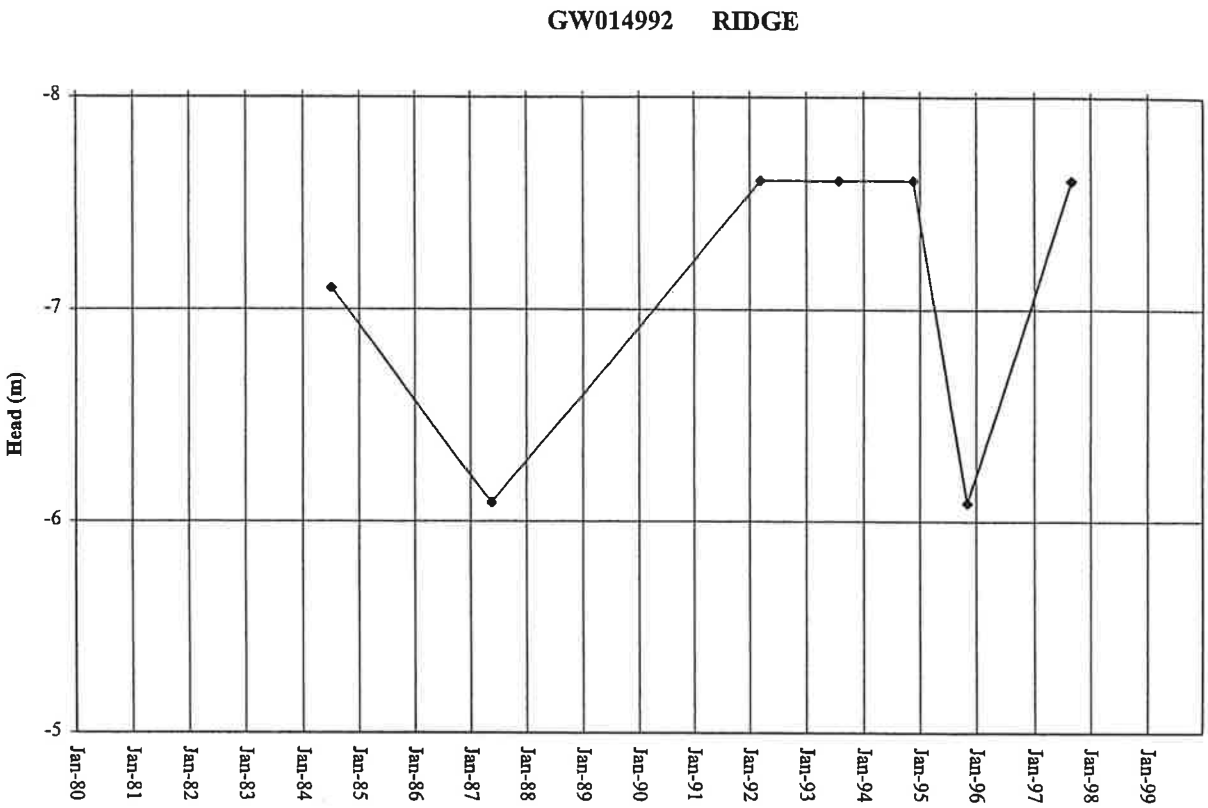
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Head (m)
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-7
-6
-5
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
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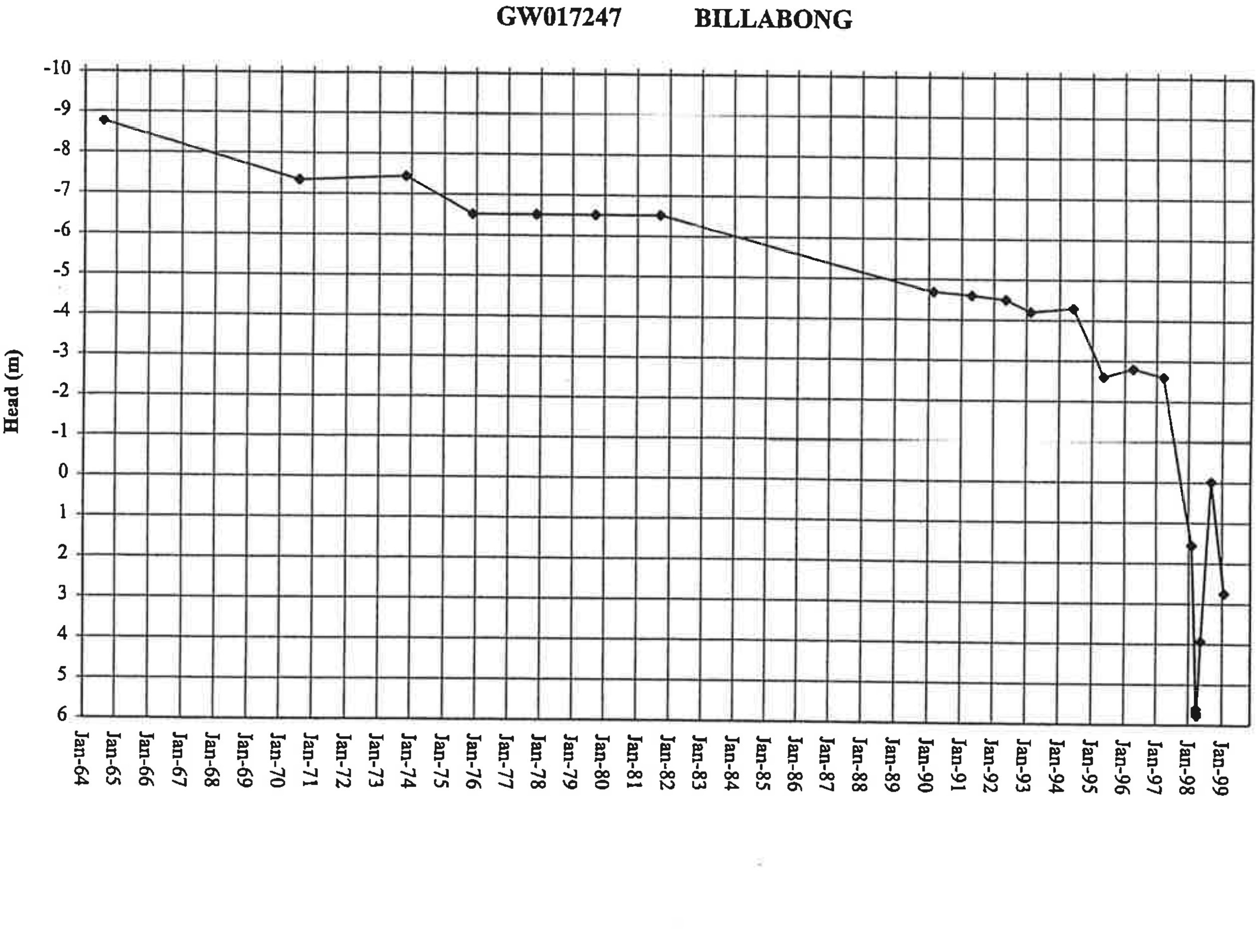
Jan-98
Jan-99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Head (m)
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-8
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-6
-5
-4
-3
-2
-1
0
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6
Jan-64
Jan-65
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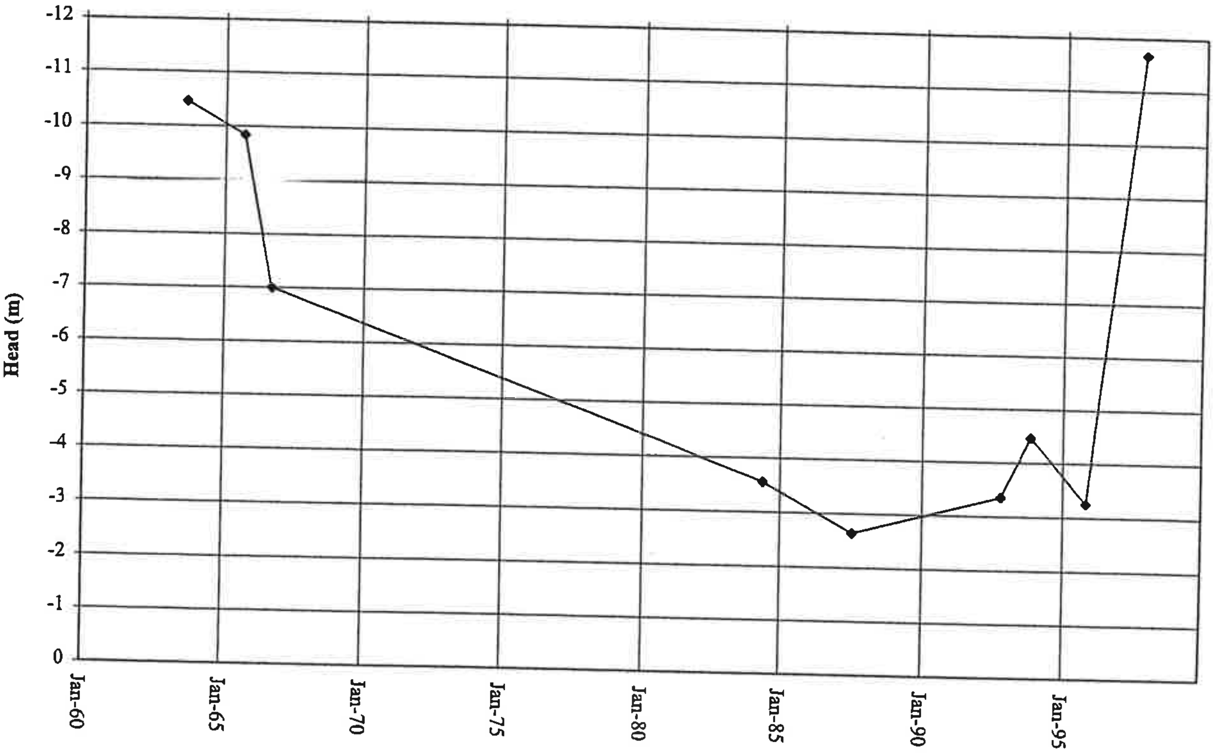
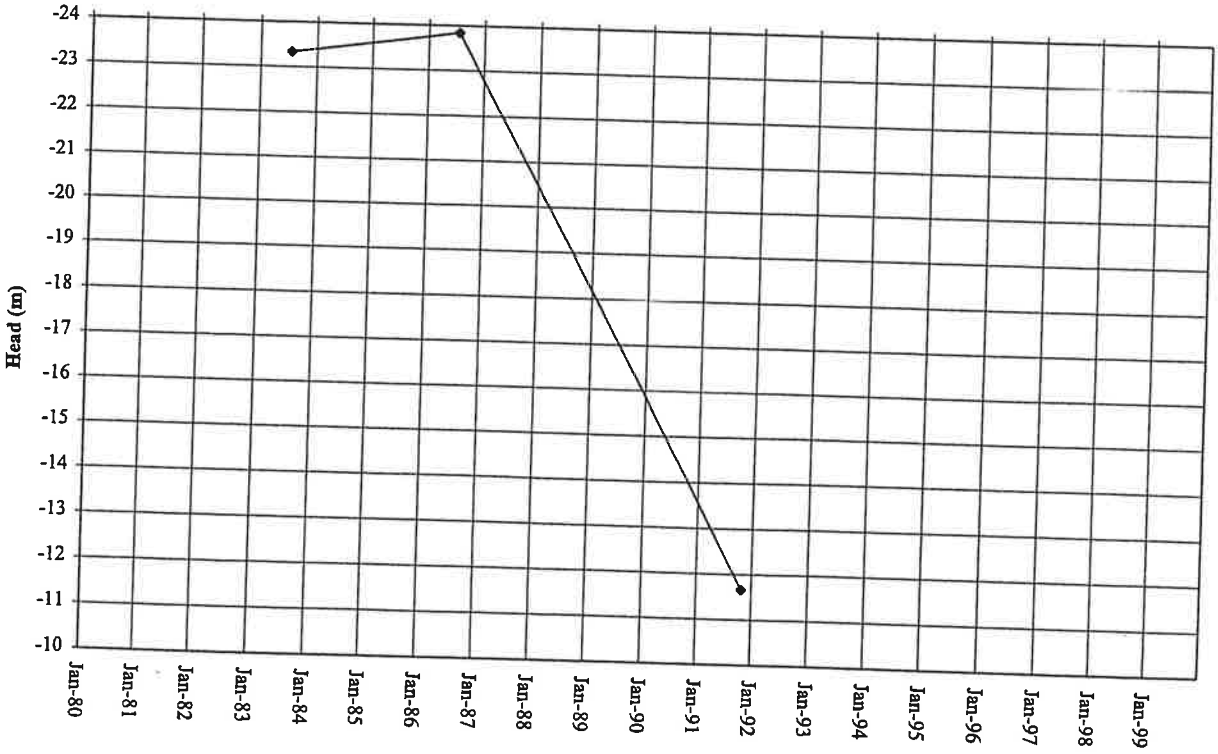


GW019373 PEERY



GW030963 SANDHILL