# Social and Ecological Impact of Water Extraction for a Copper-Uranium Mine

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## Abstract

Mining activities often take place in relatively remote regions of the world where water is a limiting resource and infrastructure to harness water is minimal. Copper-uranium mining at Olympic Dam in South Australia provides an interesting example of such a situation. The mine's water supply is sourced from the south-western margin of the Great Artesian Basin, one of the Basin's principal groundwater discharge zones where over several millennia unique springs have formed. These springs contain many rare and endemic flora and fauna and were important foci for the traditional people of the region. The social and ecological costs of rapid water extraction are often not accounted for in such ventures because the short-term gains from mineral extraction are enormous and occlude more long-term environmental impacts on water availability. Indeed, the life of a mine is usually no more than half a century but the effect of the mining on water resources is often irreversible. The small settlements of native groups that inhabit such regions have historically been excluded from the decision-making process concerning such mines. Long-term planning for water resource extraction at the Olympic Dam mine is thus an increasingly important task in order to protect the associated environmental and cultural values of the springs.

## 1 WATER USAGE IN URANIUM MINING

There is clear evidence that mining directly affects the immediate environs of a mine project and carries significant potential for off-site impacts (Birrell *et al.*, 1982). The deleterious effects of mining were noticed as early as 1556, when Georgius Agricola wrote his seminal text on mining (Agricola, 1556) :

> "When ores are washed, the water which has been used poisons the brooks and streams. Therefore the inhabitants of these regions, on account of the devastation of their fields, woods, groves, brooks and rivers find great difficulty in producing the necessities of life."

There are significantly large quantities of waste material generated through mining since minerals are generally a rare appendage to large quantities of worthless sediment. A study conducted by UNESCO specifically highlighted 9 hydrogeological processes which can be affected by mining (Clark, 1988). These included transient groundwater flow, river flow, spring yields, limestone and marl flow, mining volumes, mineralisation of mine water and river water, water pumping and development of a cone of depression.

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Underground mining often involves rock dewatering and the lowering of piezometric head. This may in turn lead to compaction of sand and clay, alteration in rock mass, and the development of major jointing and surface subsidence (Clark, 1988).

Groundwater, the most significant source of potable water for large portions of Australia (AWRC, 1992), can be directly affected by mining. Water within a mine has traditionally been considered a hindrance to mining and hence drainage programs from the mining site may cause major disruptions in groundwater regimes. The direction of groundwater movements may easily change due to mining, thus leading to disruptions in recharge and flow regimes and the drying up of certain springs. There may also be a rise in groundwater in certain mining areas where geotechnological methods are used or where tailings impoundments are located. Contamination of springs due to seepage of mine wastes may exacerbate the problem of water quality. Highly mineralized water may be damaging to the organisms residing in rivers, not to mention the deleterious effects on humans.

The uranium found in economic ore deposits needs to be processed through several steps in order to extract a usable product. At underground mines the ore is often crushed before being brought to the surface for processing. The next step in the extraction process uses large quantities of water to convert the ore into a slurry that is subsequently treated in flotation tanks. The aqueous medium allows for chemical reagents to be added to the ore in order to dissolve the various constituent elements. The radioactivity associated with uranium ores also requires significant water usage for dust suppression across the mine site to prevent radioactive dust dispersing widely into the environment and to protect worker's health. There is also extensive water used within an underground uranium mine for spraying after blasting, washing down of walls, wetting of ore piles before moving, and at ore chutes, passes and crushers (Kinhill, 1983).

Mining operations are thus a source of great economic gain on the one hand and environmental stress on the other. Inequities in the benefits gained from mining are enormous, given the historical management of such operations. The dependence of the economies on mining results in tremendous leverage being granted to mining companies by governments. Water quality often gets eclipsed by these broader economic goals. It is sometimes even argued that by having stable economies the countries of the region can afford to extract water at much higher costs. This ostensible opulence often leads to investment in large development projects that have their own litany of environmental damages.

## 2 OVERVIEW OF OLYMPIC DAM OPERATIONS

The Olympic Dam polymetallic copper, uranium, gold and silver deposit in northern South Australia was discovered in 1975 by Western Mining Corporation (now WMC) and contains the largest known uranium ore body in the world (Roxby Downs is the name of the pastoral station and township, although the Olympic Dam mine is colloquially known as Roxby Downs). The deposit was developed as a joint venture between WMC (51%) and British Petroleum (BP, 49%) (Kinhill, 1997). After the operation of pilot plant studies in the mid-1980's, a commercial mine began operation in 1988 and is currently nearing completion of a major expansion. WMC acquired full ownership of the mine in 1993 and it is presently ranked seventh as a world producer of uranium (Uranium Institute, 1998).

The Olympic Dam mine currently produces about 85,000 tonnes per annum (tpa) of refined copper, 1,600 tpa of uranium oxide ($U_3O_8$), 13 tpa of silver and 850 kg per year of gold (Kinhill, 1997). The State and Commonwealth governments approved the development of the mine in 1983. In 1997, a formal proposal was made to expand production in two stages to 200,000 tpa of copper and associated products, and further to 350,000 tpa of copper and associated products (Kinhill, 1997). However, only the expansion to levels of 200,000 tpa of copper, 4,630 tpa of uranium oxide, 23 tpa of silver and 2 tpa of gold was approved by State and Commonwealth governments due to the lack of detail on the expansion to the 350,000 tpa of copper level (Assessment Report, 1997).

The ore reserves of the multi-mineral deposit are large by any standard, with 11.4 million tonnes (Mt) of copper, 340,000 tonnes of uranium (as $U_3O_8$), 2,790 tonnes of silver and 400 tonnes of gold (Kinhill, 1997). The reserves may be in excess of 30 Mt copper, 1.2 Mt uranium (as $U_3O_8$), 7,000 tonnes of silver and 1,200 tonnes of gold, as further exploration continues to delineate the actual extent of economic mineralisation (Campbell *et al.*, 1998). The deposit is also strongly enriched in rare-earth elements (REE), making it one of the largest concentrations of these metals in the world (Reeve *et al.*, 1990), although these are not extracted. The expanded production rate and large reserves will allow production from the mine for at least the next 50 to 100 years.

The process and potable water supply for the Olympic Dam mine and Roxby Downs township is derived from two borefields located approximately 120 to 200 km to the north, around the south-western margins of the Great Artesian Basin near Lake Eyre South. Since the start of pilot plant operations and the commercial mine, the amount of water extracted has steadily increased, with extraction during 1996 averaging about 15 Ml/day (ODC, 1997). The borefields are located directly within or near the Lake Eyre supergroup of mound springs (Mudd, 1998). The original 1982 Environmental Impact Statement (EIS) (Kinhll, 1982) and 1997 Expansion Project EIS (Kinhll, 1997) predicted impacts on the springs as well as other users of GAB water in the region. However, the actual impacts have been markedly different.

The northern regions of South Australia are arid to semi-arid, with evapotranspiration generally exceeding rainfall by an order of magnitude or more (Allan, 1990; Badman *et al.*, 1996). The surface landscape has seen dramatic change over the past 500 million years, varying from shallow seas with active volcanoes, glaciers and ice caps, rich humid and tropical forests, to the dry arid landscape now present (Krieg *et al.*, 1990). Each climate has left distinctive marks on the landscape.

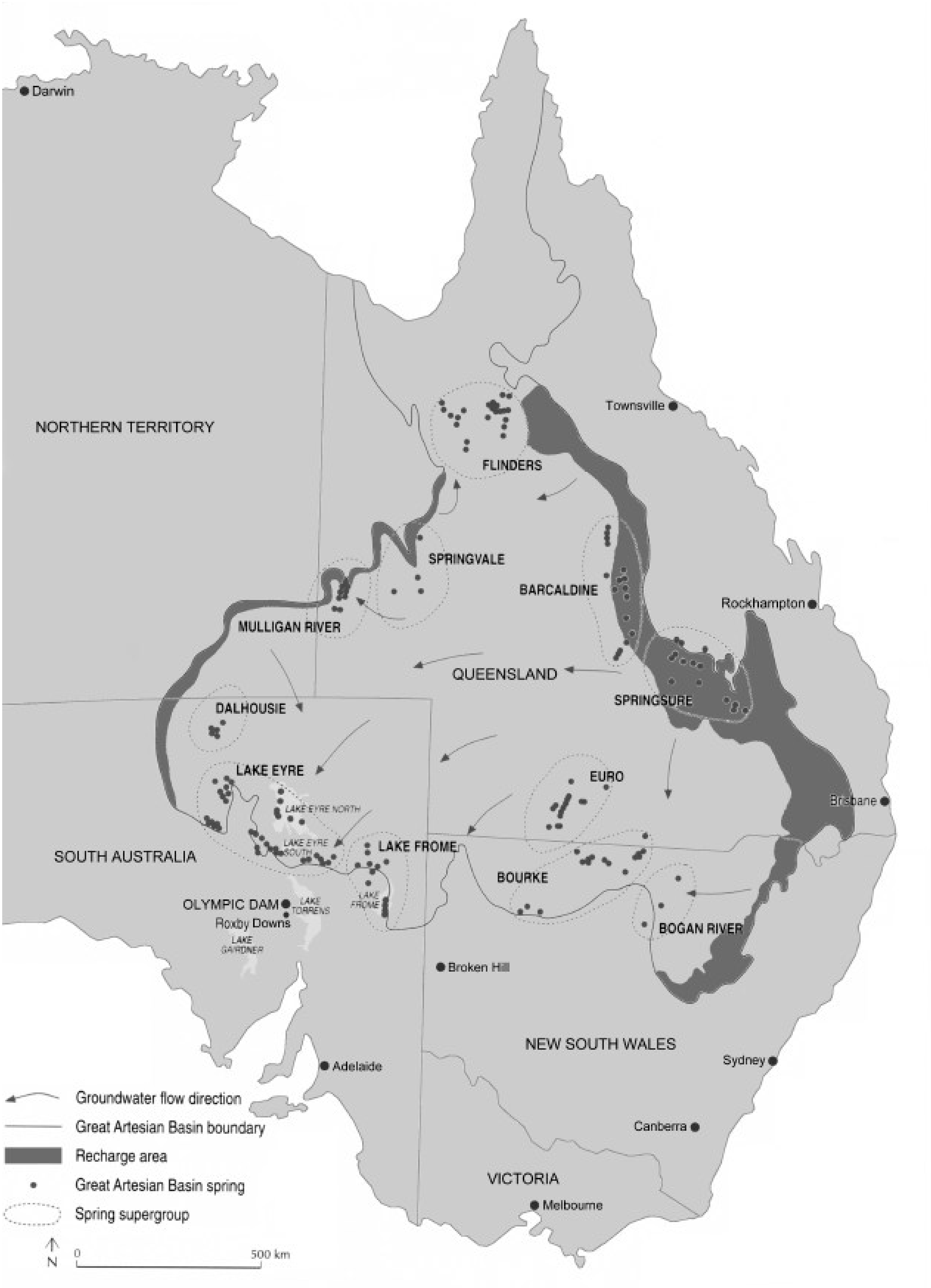
The availability and careful management of water supplies is thus critical to the overall project and it’s related environmental impacts.

# 3 THE GREAT ARTESIAN BASIN

## 3.1 Overview of Hydrogeology

The Great Artesian Basin (GAB) is one of the world's largest and oldest groundwater system, underlying 22% of the Australian continent or 1,711,000 km$^2$ (Hillier, 1996). It consists of several contiguous sedimentary basins with confined aquifers of Triassic, Jurassic and Cretaceous continental quartzose sandstones, underlain by an impervious pre-Jurassic base (Habermehl, 1996a). The aquifers are confined by the Rewan Group at the bottom and the Winton Formation at the top (Habermehl, 1980). The maximum total thickness of about 3,000 metres occurs in the Mesozoic sedimentary sequence in the central GAB. The Basin forms a large synclinal structure, uplifted and exposed along it’s eastern margin, leaving the overall Basin tilted southwest (Keane, 1997).

Figure 1 - Location of the Olympic Dam Project and the Extent of the Great Artesian Basin, Flowpaths and Spring Groups (Kinhill, 1997)



Recharge to the GAB occurs primarily along the uplifted eastern margins and also on the western margins where the aquifers are exposed or overlain by sandy sediments (Habermehl, 1980). Environmental isotope and other hydrochemical studies of groundwater from across the Basin confirm the assumptions of continuous recharge from geological to modern times, and that the water is of meteoric origin (Airey *et al.*, 1983; Bentley *et al.*, 1986; Torgersen *et al.*, 1991; Habermehl, 1996a). The age of the groundwater, determined from extensive carbon-14 and chlorine-36 studies and correlated with hydraulic modelling studies, ranges from several thousands of years near recharge areas to nearly two million years around the southwest of the GAB near Lake Eyre (Habermehl, 1996a).

Natural discharge from the GAB occurs via two principal processes - vertical leakage towards the regional water table and concentrated outflow from springs around the margins (Habermehl, 1996b). Since the onset of European development of the GAB for the pastoral industry late in the 19$^{TH}$ century, and more recently the mining and resource extraction industries, discharge via free or controlled artesian bores and pumped abstraction from non-artesian bores has now become the primary discharge mechanism (Keane, 1997).

The hydrochemistry of the majority of the GAB is dominated by sodium-bicarbonate-chloride waters, although waters around the western margin are of a sodium-sulphate-chloride type (Habermehl, 1980). The total dissolved solids (TDS) of groundwater generally increases with the depth of the aquifer being tapped, with the Lower Cretaceous-Jurassic aquifer containing good quality water with a TDS from 500 to 1,000 mg/l. The water in the shallower Cretaceous aquifers have higher salinities up to a TDS of 10,000 mg/l (Habermehl, 1980). The surface temperature of groundwater from waterbores tapping the Lower Cretaceous-Jurassic sequence ranges from 30° to 100° C, while the temperature of water from artesian springs are generally between 20° and 45° C (Habermehl, 1996a). The heat flow in the GAB is attributed to heat produced in the earth's crust by uranium and thorium, and by recent volcanic activity Torgersen *et al.*, 1992).

### 3.2 Mound Springs

A unique feature of the GAB is the large numbers of springs it supports. There are considered to be 11 main groups totalling about 600 individual springs, with the Lake Eyre supergroup around the south-western margin containing the largest concentration of active and unique springs (Habermehl, 1982). The location of springs is controlled by local geology, such as faults or erosion of confining beds (Boyd, 1990; Keane, 1997). The flow rates from individual springs are highly variable, with values ranging from 0.1 to 14 Ml/day, with the majority being less than 0.5 Ml/day (Habermehl, 1982 & 1996b).

The persistence of spring flows over geologic time has seen the accumulation and carbonate cementation of sand, silt and clay, building a characteristic mound. Hence these particular springs, found only in the Lake Eyre supergroup, are referred to as Mound Springs. A typical mound consists of a central pool of water, an outer rim of reeds and vegetation, an outflow channel, and successive layers of carbonate. The mounds may be up to 8 m in height and up to 30 m in diameter across (although the extinct Hamilton Hill Spring is about 40 m above ground level, suggesting that artesian pressures have been higher in the GAB over recent geologic time) (Habermehl, 1982).

A wetland and sometimes a small creek are formed by the outflow from a spring. The flowrate from a spring has been shown to be directly proportional to the area of wetland vegetation a spring supports (Williams & Holmes, 1978; Fatchen & Fatchen, 1993). This "environmental flow" is critical in the ability of a spring to support it's surrounding wetland.

There are numerous factors known to influence the observed flow rate from a spring. These include diurnal and other variations in atmospheric pressure (barometric effects), evaporation rates, vegetation communities on the mound springs, and pastoral impacts (Kinhill, 1997). In practice, these factors are hard to account for quantitatively and are typically ignored in compiling variations and long-term changes in spring flow rates.

Figure 2 - Cross Section of an Ideal Mound Spring (after Williams & Holmes, 1978)

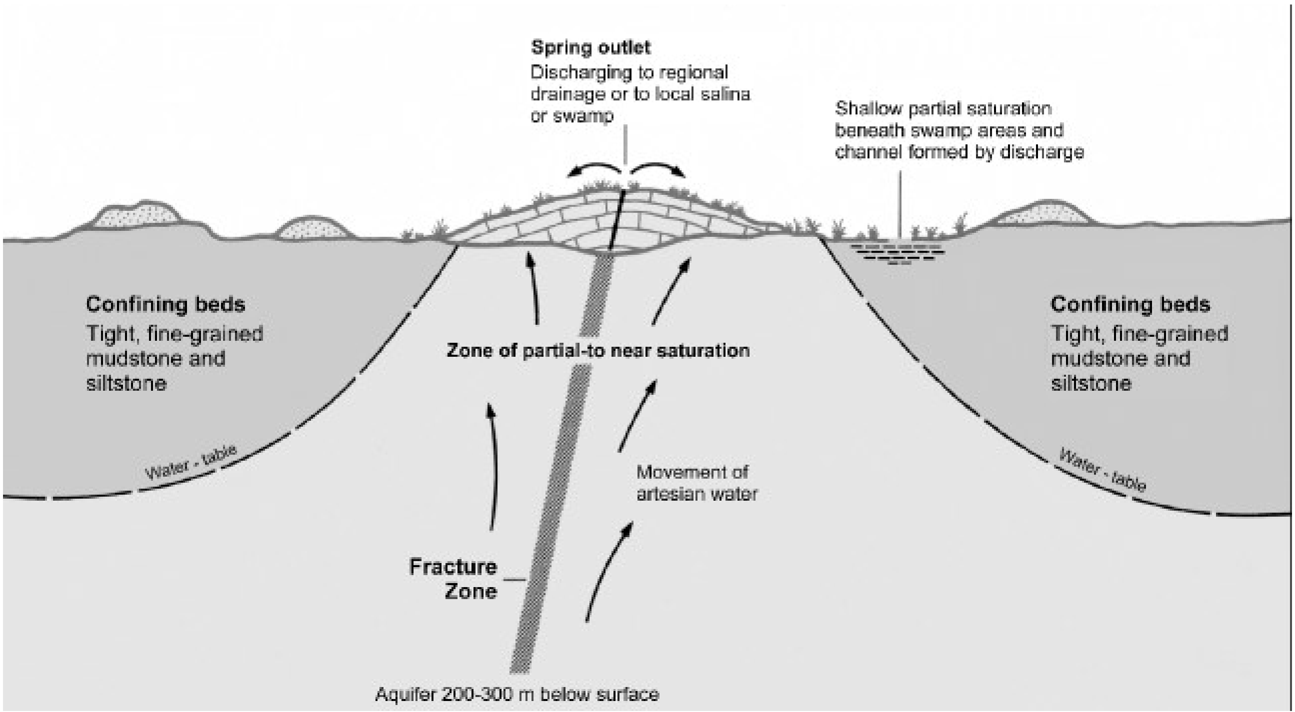
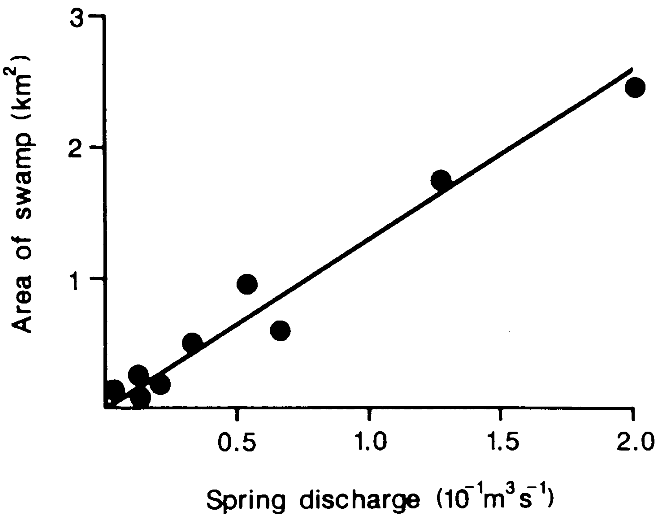



Figure 3 - Wetland Area vs Spring Discharge (Williams & Holmes, 1978)




## 3.3 Ecological Value of a Mound Spring

The Mound Springs are the only permanent source of water in the arid interior of South Australia and a delicate yet intricate ecological balance has been established (Keane, 1997). Due to their prolonged isolation the mound springs contain many rare and endemic species that have undergone genetic differentiation and speciation (Noble *et al.*, 1998; Kinhill, 1997). The springs are important as drought refuge areas for much wildlife and as wetlands for migratory birds, recognised as being of national importance (DHAE, 1983; ANCA, 1993).

The rare and endemic species include plants, fish, hydrobiids, isopods, amphipods and ostracods, many of which occupy specialised areas within a spring such as the open pool, outer rim or the rocky outflow channel (Ponder & Jenkins, 1983; Keane, 1997). Despite the linear correlation of flow rate with wetland area, a minor reduction of flow of the order of 20% can impact animal populations by up to 70%, although current monitoring only counts total population and not individual species dynamics (Ponder & Zeidler, 1997). Many species are only found within a particular mound spring or spring complex (Habermehl, 1996b). The mound springs provide unique opportunities for prehistoric, evolutionary, ecological and biogeographical studies.

### 3.4 Indigenous Heritage of the Springs

The springs were a vital resource for the Aboriginal inhabitants of the region for many thousands of years and remain so to this day (Keane, 1997; Hercus & Sutton, 1985; Habermehl, 1996b; Noble *et al.*, 1998). This is evidenced by the abundance of stone chips, grinding stones and other traditional tools in the vicinity of the springs, and also by the rich mythological and oral history of the springs in local Aboriginal culture (DHAE, 1983; Hercus & Sutton, 1985). The springs in the Lake Eyre region are recognised as being under the traditional custodianship of the Arabanna people (Hercus & Sutton, 1985; Keane, 1997).

All individual springs and complexes are known to hold significance to Aboriginal people, and it is impossible in modern times to predict, with any confidence, that an individual mound spring does not have any significance due to similarities with other springs in an area (Noble *et al.*, 1998). Hercus & Sutton (1985) emphasize that “the springs are considered so important that the large-scale deterioration of any group of springs would cause great distress to at least some Aboriginal people, whether their associations with the sites are direct or indirect.”

## 4 HYDROGEOLOGICAL IMPACT OF THE OLYMPIC DAM BOREFIELDS

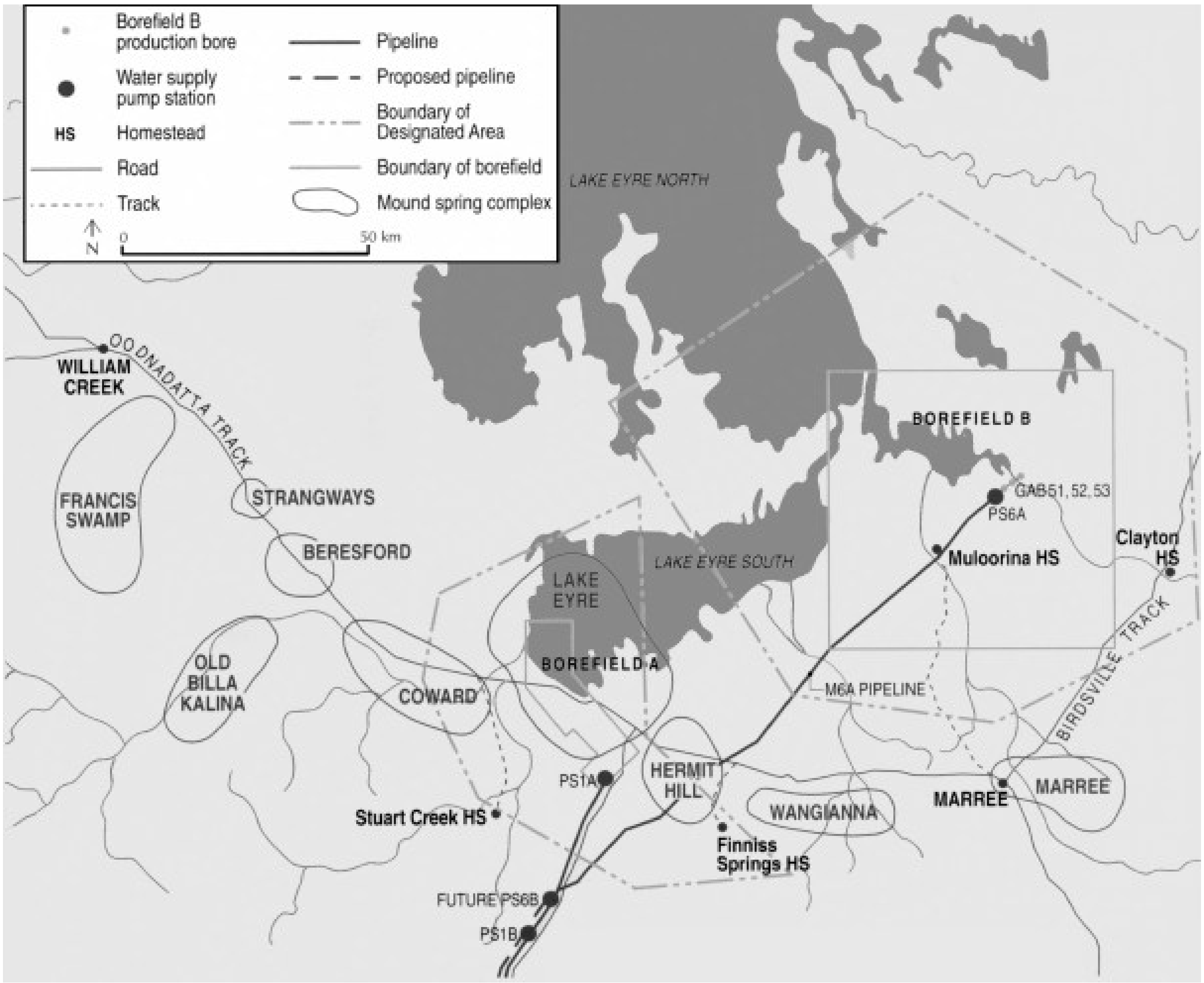
### 4.1 Overview of the Water Supply Borefields

The initial investigations for a water supply for the Olympic Dam Project in the late 1970’s concentrated on an area deep into the GAB north-east of Marree, with the Clayton No. 2 bore being drilled in 1980 by the then Commonwealth Bureau of Mineral Resources, Geology and Geophysics (now the Australian Geological Survey Organisation, AGSO) as an investigation bore of the hydrogeologic properties of the GAB for a large borefield in this region (Habermehl, 1998).

The proposal given in the Draft Environmental Impact Statement in 1982 (Kinhill, 1982), however, presented two borefield’s A and B, located closest to the mine, in the midst of the Lake Eyre group of mound springs. Borefield A was on the southern margin of the GAB, close to the Bopeechee, Venables, Hermit Hill, Sulphuric and numerous spring groups, while Borefield B was to be 50 km further into the GAB closer to Lake Eyre South. The proposed extraction rates of 6 and 27 Ml/day from Borefields A & B were via 5 bores and 7 to 10 bores respectively, pumped via pipeline to Olympic Dam (Kinhill, 1982).

There are two important hydrogeologic principles behind placing the borefields in this region. Firstly, to harvest vertical leakage that is otherwise discharged to shallow, saline water tables and lost to surface evaporation (Kinhill, 1982, 1984 & 1997). Secondly, Borefield A was within a geologic sub-basin thought to be hydraulically separated from the mound springs by the Norwest Fault Zone (Kinhill, 1984; Berry & Armstrong, 1995 & 1996), although this approach is not explicit in Olympic Dam Project literature (eg - Kinhill, 1982 & 1997).

Figure 4 - Location of Borefields A & B and Mound Spring Complexes (Kinhill, 1997)




The first bore from the southern region of Borefield A commenced extraction in late 1983 at approximately 1.3 Ml/day, increasing in January 1987 to about 2.5 Ml/day (ODO, 1992). It is explicitly stated in Kinhill (1982) that Borefield A, developed and commissioned during initial mine construction, would not be able to supply the total demand for water of commercial mining operations and that Borefield B would be necessary for such a scale of operations. The remaining series of bores forming the southern and central regions of Borefield A were commissioned over 1987-88, totalling about 10.8 Ml/day (ODO, 1992).

By commissioning of the mine in 1988, however, investigation, design and development of Borefield B was yet to begin. It was clear that the demand for water and the average extraction rate from Borefield A would exceed the original projection. A new proposal was approved by the South Australian government in 1991 to allow expansion of Borefield A with new limits on drawdowns at the designated boundary until construction of Borefield B (WMC, 1995). Three new extraction bores were commissioned in January 1992 on the southern shores of Lake Eyre South (Kinhill, 1995a).

Planning and investigation for the construction of Borefield B finally commenced in 1992 and field geophysics indicated that the original site would be unsuitable due to various constraints, such as no hydraulic barrier and excessive impacts on springs (Berry & Armstrong, 1996). A new site was selected based upon existing exploration seismic data 50 km to the north-east of the original site, where the GAB thickens and becomes more permeable (Berry & Armstrong, 1996). Operation of the first bore from Borefield B began in November 1996, supplying approximately 9-10 Ml/day and extraction from Borefield A was reduced to 5 to 6 Ml/day (Kinhill, 1997).

Table 1 - Average Extraction Rates from the Olympic Dam Borefields (Kinhill, 1997)

| Years | Borefield A (Ml/day) | | | | Borefield B | Total |
|---|---|---|---|---|---|---|
| | Southern | Central | Northern | Total | (Ml/day) | (Ml/day) |
| 1982-86 | 1.30 | 0 | 0 | 1.30 | 0 | 1.30 |
| 1986-87 | 2.30 | 0 | 0 | 2.30 | 0 | 2.30 |
| 1987-88 | 2.34 | 2.08 | 0 | 4.42 | 0 | 4.42 |
| 1988-89 | 4.27 | 4.56 | 0 | 8.83 | 0 | 8.83 |
| 1989-90 | 5.68 | 4.30 | 0 | 9.98 | 0 | 9.98 |
| 1990-91 | 6.25 | 4.39 | 0 | 10.64 | 0 | 10.64 |
| 1991-92 | 5.67 | 4.39 | 1.57 | 11.63 | 0 | 11.63 |
| 1992-93 | 5.60 | 3.98 | 3.01 | 12.59 | 0 | 12.59 |
| 1993-94 | 4.50 | 3.14 | 4.46 | 12.10 | 0 | 12.10 |
| 1994-95 | 4.72 | 4.37 | 4.43 | 13.52 | 0 | 13.52 |
| 1995-96 | 4.67 | 5.40 | 4.92 | 14.99 | 0 | 14.99 |
| 1996-97 | n/a | n/a | n/a | 6.9 | 7.8 | 15.20 |

## 4.2 Hydrogeological Impacts

By the early 1990's it was apparent that impacts on the mound springs were underestimated in Kinhill (1982). By 1990 the spring vents at Priscilla and Venables had ceased flowing, and there were visible reductions in flows and wetland area at other spring complexes, notably Hermit Hill, Beatrice and Bopeechee (Keane, 1997).

The approach of Kinhill (1997) for the proposed expansion of Olympic Dam and the borefields was to compare all spring flow rates to 1996 levels, and not pre-borefield levels. It is unclear why this was done, but the relatively small changes presented do not compare favourably to the much larger changes from background flows. The predicted graphs of spring flows in Kinhill (1997) display downward trends after three years, with the relative reduction from 1996 levels ranging up to 17%.

A comprehensive table has yet to be compiled comparing background, current and predicted flows from springs and bores, although background data is incomplete. A brief compilation is attempted in Table 5 for some of the more important springs, although it can only be considered indicative until a more thorough compilation of monitoring data is undertaken.

Table 2 - Reduction in Mound Spring Flows - Predicted# and Actual (Kinhill, 1997)

| Spring Complex | Spring Name | Predicted Flow Reductions (%) | | Actual Flow Reduction (%) |
|---|---|---|---|---|
| | | Impermeable | Semi-permeable | |
| Hermit Hill | Beatrice | 100 | 100 | 40 |
| | Bopeechee | <2 | 20 | 43 |
| | Hermit Hill | <1 | <1 | 36 |
| | Old Finnis | <2 | <2 | marginal increase |
| | Venable | 100 | 100 | 100 (extinct May 1990) |
| Wangianna | Davenport | <1 | <1 | close to 0 |
| Lake Eyre | Emerald | 3 | 3 | close to 0 |
| | Fred | 6 | 17 | 50 |
| | Priscilla | 75 | 60 | 100 (extinct late 1990) |

# - predictions based on the northwest fault zone being impermeable or semi-permeable (Kinhill, 1984).

Table 3 - Select Background and Current Spring Flows (kl/day) (Mudd, 1998)

| Spring | 1974[1] | 1981[2] | 1985[3] | 1988 | 1991 | 1992 | 1993 | 1996 | 1997 |
|---|---|---|---|---|---|---|---|---|---|
| Venable (pastoral bore) | - | - | 180 | 124 | 24.4 | 11.6 | 2.6 | n/a | 0.0 |
| Hermit Hill Complex | 130 | 30 | 45.4 | 31.1 | 36.3 | 36.9 | 37.1 | 30.2 | - |
| Old Finnis | - | - | 14.2 | 14.7 | 13.0 | 13.0 | 13.8 | 13.0 | 11.2 |
| Beatrice (pastoral bore) | 130 | 25 | 63.1 | 58.8 | 39.7 | 27.1 | 34.6 | n/a | 25.9 |
| Bopeechee | 130 | 25 | 54.4 | 42.5 | 33.7 | 33.5 | 31.7 | 24.2 | 13.9 |
| Fred | 40 | 10 | 15.6 | 4.3 | 9.1 | 4.7 | 12.0 | n/a | - |

[1] - includes flow and evapotranspiration. [2] - flow only.
[3] - Reference flows used by WMC for comparison.
(Pastoral bores are adjacent to the former spring vents at Venables and Beatrice).
Compiled from Kinhill (1982), A Lad (pers. comm.) and Annual Environmental Management Reports by WMC.

There are a number of complex mitigating factors in determining the reasons for the variability and reductions in spring flow. However, it is clear that the location and subsequent expansion of Borefield A in the midst of the springs hastened the demise of some springs and flow reductions in others.

Some key considerations in discerning the impact of Borefield A on the springs are (Mudd, 1999) :

- it was widely recognised at the time of the Draft EIS that there was a significant deficiency in the amount of knowledge and data on the hydrogeology of the southern margins of the GAB, especially the mound springs (eg - Kinhill, 1982 & 1983; DEP, 1983; DHAE, 1983);
- original projections of spring flow reduction did not include a significantly expanded rate of extraction from Borefield A;
- flow across the Northwest Fault zone was assumed to be impermeable, whereas operation of Borefield A demonstrated a degree of hydraulic connection (Berry & Armstrong, 1995). It is hypothesized that the higher extraction rates created an increased pressure difference across the fault zone than early field testing and operation achieved, and thus the system was not stressed to the point of becoming permeable until Borefield A was expanded;
- the interpreted geological structure based on aerial photography presented in ODO (1993) shows that, like many springs across the GAB, several springs in the vicinity of Lake Eyre South are located directly above or near fault zones (eg - McLachlan, Smith and Fred Springs) - suggesting that faults are at least semi-permeable across the region;
- the rehabilitation of pastoral bores in the Lake Eyre region is improving efficiency of water extracted for pastoral purposes, reducing demand from this source and associated impacts on spring flows (Sampson, 1996);
- Woods (1990), using environmental isotope techniques to study the evaporative loss from the water table which receives vertical leakage from the GAB aquifer, concluded that the sustainable yield of Borefield A was approximately 9 Ml/day (the average extraction during 1990 was 10.6 Ml/day);
- pastoral bores are generally low yield bores spread diffusely across a large area while the borefields contain high yield bores in the concentrated region of the mound springs;
- the extraction of water by production bores is via pumps, thereby exacerbating drawdowns, whereas pastoral bores flow under natural artesian conditions;
- the volume of water extracted by the borefields represents a significant alteration to the water balance of the Lake Eyre region (refer Table 2), with only 2 Ml/day of spring flow and up to 15 Ml/day for Borefield A. Further expansions of the borefields in the vicinity will exacerbate the impacts on the Lake Eyre region of the GAB;

- predicted impacts on spring flow are determined on the basis of reduction in artesian pressure only (eg - Kinhill, 1984), not accounting for barometric effects or other factors known to influence spring flows. The Bopeechee and Hermit Hill spring complexes are fed from shallow and not deep GAB aquifers, and the assumption of artesian head driving spring flow may therefore be innaccurate (Berry 1995). Fatchen and Fatchen (1993) state that there is no clear relation between pressure head and spring flow.
- the groundwater computer modelling undertaken to predict the impact of the borefields on the GAB and the mound springs (eg. Berry & Armstrong, 1995; Armstrong & Berry, 1997), contains many conceptual uncertainties which preclude any confidence in the predictions (such as no presentation of a conceptual approach for modelling the impermable or semi-permable behaviour of the Norwest Fault zone).

## 5 SOCIAL AND ECOLOGICAL IMPACTS

### 5.1 Overview of Ecological Impacts and Threats

Water is clearly a limiting resource in the region, particularly since its principal source is “fossilized” water from the Great Artesian Basin. The flora and fauna of the area are almost entirely dependent on surface expressions of groundwater for survival. The ecological salience of desert regions is often neglected because of harsh climatic conditions and a general perception that dry areas are devoid of life. While some desert regions are clearly “barren”, the region of the South Australian desert from where the water for Olympic Dam is extracted is recognized internationally as possessing unique ecological features. There are approximately 150 species of plants, 15 species of mammals, 50 species of reptiles and 100 species of birds in the region (MAPC, 1993). The species of birds which have been listed as threatened by the Royal Ornithological Union are in Table 3 (MAPC, 1993).

Disruption of the microecology of the region as a result of water extraction was evidenced by a misplaced conservation proposal in the 1980’s to transplant a rare indigenous plant species *Eriocaulon carsonii* in a region where it does not naturally occur (Kinhill, 1997). There are, however, some species which have benefited as a result of the increased surface water supply in the Roxby Downs area, most notably, the Crested Pigeon, the Zebra Finch and the Common Starling.

Table 4 - Species Threatened by Anthropogenic Activities for Olympic Dam (MAPC, 1993)

| Common Name | Scientific Name |
|---|---|
| Spotless Crake | *Porzana tabunsis* |
| Australian Dotterel | *Peltohyas australis* |
| Banded Stilt | *Cladorhynchus leucocephalus* |
| Australian Bustard | *Ardeotis australis* |
| Brolga | *Grus rubicundus* |
| Freckled Duck | *Stictonetta naevosa* |
| Spotted Harrier | *Circus assimilis* |
| Black-breasted Buzzard | *Hamirostra melanosteron* |
| Black Falcon | *Falco subniger* |
| Blue-winged Parrot | *Neophema chrysostoma* |
| Gibberbird | *Ashbyia lovensis* |
| Banded Whiteface | *Aphelocephala pectoralis* |
| Thick-billed Grasswren | *Amytornis textilis* |
| Painted Firetail | *Emblema picta* |

## 5.2 Aboriginal Association with the Water Resources of the Region

Archaeological investigations in the region have revealed evidence of aboriginal habitation as far back as 26,000 years before present (Kinhill, 1985). Due to the hunter-gatherer nature of aboriginal society, it is also very difficult to delineate tribal domain over areas of land. Indeed there was no formal system of property rights in aboriginal society and hence anthropologists have struggled to demarcate ancestral lands for mining projects. The legitimacy of certain native claims were therefore subject to scrutiny from anthropologists who had widely differing views. Archeological evidence was the primary means that the company used in its determination of aboriginal claim. The Environmental Non-Government Organisations (ENGOs) attempted to present anthropologists that could perhaps legitimize the claims of the aboriginal groups who were supporting their cause. However, since very few of the aboriginal people were actually living near the mine itself (and were themselves residing in nearby cities), the claims were difficult to defend.

Some notable anthropologists did, however, challenge the mining companies assertions but were largely ignored. Given the scholarly disagreement in aboriginal anthropology the company should have given more considerations to differing views. WMC primarily relied on the studies conducted by linguistic anthropologists such as Hercus and White (1973) and Davis and Prescott (1992). Peter Sutton, one of Australia’s most distinguished anthropologists, largely disagreed with the delineation of aboriginal territory which WMC used. The company’s lawyers also relied on the work of a highly controversial ethnographer, Dean Fergie, who had previously been cited in another aboriginal grievance surrounding the Hindmarsh Islands.

The area where the borefields are located have been contested by Arabanna and Dieri Mitha acommunities during the course of the mining negotiations. Apart from being a perennnial source of water for subsistence, the mound springs are of immense cultural and spiritual significance to Aboriginal people. Particular associations with the topography of certain areas constitute their perennial mythology, known as “Dreamtime.” There are several Dreamtime stories associated with the springs. For example, the movement of water in the Bubbler spring are described as convulsions of the Ganmari snake, killed there by a Kuyani ancestor.

Inevitably within Aboriginal communities there is a range of opinions regarding the protection of sacred and significant sites. Mining companies are often willing to offer compensation for the usage and disturbance of Aboriginal land. This economic incentive plays on the differences in opinion within the community. However, instead of following a consensus-building process in which various points of view can be voiced, the negotiations over the water usage at the mine were relatively unilateral. Though public meetings were held at various times, the mining company chose to negotiate only with the Aboriginal group that was most agreeable to mining, the Dieri Mitha Council. Most of the members of this group did not in fact live near the water source but were residents of Port Augusta and neighbouring towns. Their claims were premised on archeological studies rather than present occupation.

On the other hand, the Arabanna community, living in Marree, were situated within kilometers of the springs but because of their vehement opposition to excessive water extraction, they were largely sidelined in the process of negotiation. This disparity in representation led to a widening rift between the two groups culminating in a violent clash between the Dieri Mitha Council and the Arabanna in January 1995 in which one person was killed. The situation has since calmed considerably. However, there is a continuing sense of deprivation in the community.

## 6 WATER POLICY AND GROUNDWATER MANAGEMENT

The first bore to tap the GAB was in 1878, drilled near Burke, NSW (Habermehl, 1980). Initially, bores were drilled near springs as these were known sources of artesian water, but the extensive areal nature of the GAB quickly became established and further deep bores were drilled in the central parts of the GAB (Habermehl, 1980). The combined flow rate from all bores across the GAB peaked early this century in 1918 at over 3,000 Ml/day, compared to current bore discharge of about 1,500 Ml/day (Habermehl, pers. comm., 1998). Many of the early bores now exhibit significantly reduced flows due to the release of water from elastic storage and are now approaching steady-state flows (Habermehl, 1996a).

Estimates of the overall water balance for the GAB reflect both the difficulty of calculations on such a large scale and the scarcity of reliable regional data (Keane, 1997). Based upon the available piezometric evidence, it is thought that the GAB has reached a new equilibrium condition, where recharge approximates total discharge (Habermehl, 1980, 1996a & 1996b).

Table 5 - Water Balance Estimates of the GAB (Ml/day) (adapted from Keane, 1997)

| Year | Recharge | Bores | Vertical Leakage | Springs | Total Discharge |
|---|---|---|---|---|---|
| 1980 | 3,024 | 1,500 | 1,394 | 130 | 3,024 |
| 1982 | 3,100 | 1,500 | 1,400 | 200 | 3,100 |
| 1997 | 2,630 to 2,930 | 1,200 to 1,500 | 1,300 | 130 | 2,630 to 2,930 |
| 1998# | *ND* | 1,200 to 1,500 | 1,100 ? | 130 | 2,815 to 3,115 |

# - Habermehl, pers. comm. (November, 1998) *ND* - No Data

Table 6 - Water Balance Estimates of the South Australian Portion of the GAB (Ml/day) (Keane, 1997)

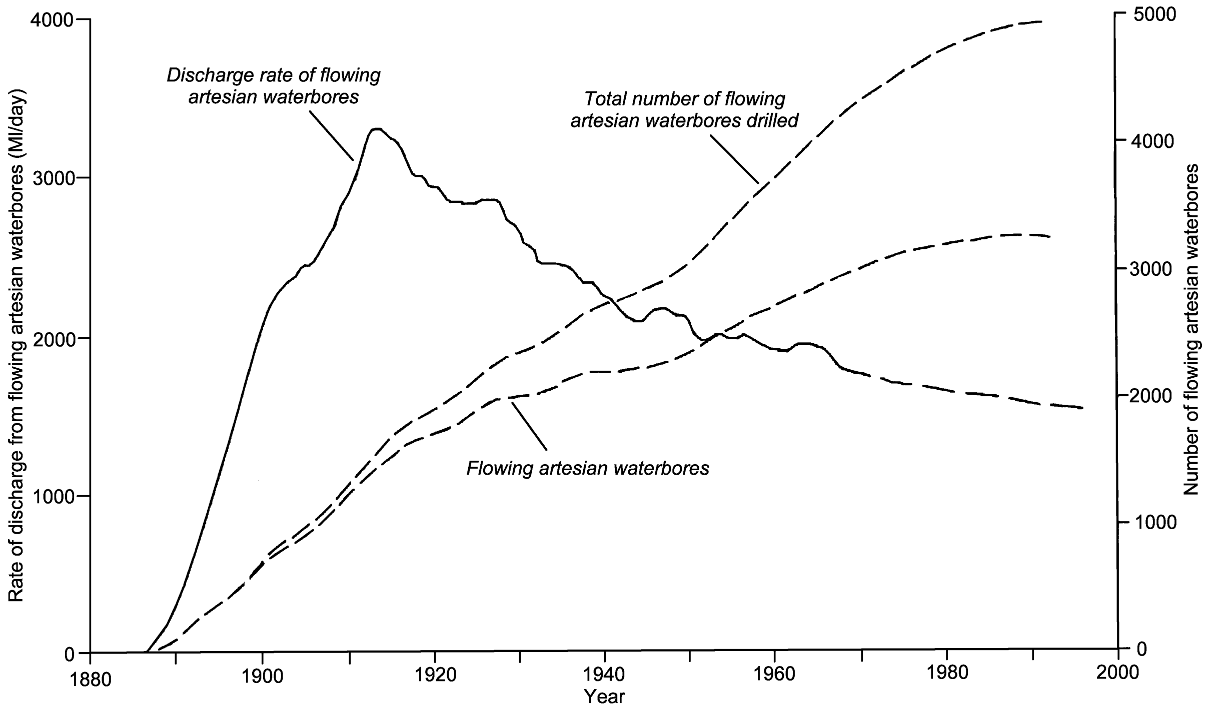
| Year | Inflow | Pastoral | Springs | Oil & Gas | Vertical Leakage | ODO | Total Discharge |
|---|---|---|---|---|---|---|---|
| 1982 | *ND* | 210 | 80 | ND | 250 | *ND* | 540 |
| 1997 | 450 | 130 | 66 | 22 | 217 | 15 | 450 |
| 1997 | 425 | 132 | 66 | 22 | 190 | 15 | 425 |
| 1995 | 350 to 400 | *ND* | *ND* | 35 | *ND* | *ND* | 350 to 400 |
| 1995# | 76 | 36 | 2 | *ND* | 24 | 14 | 76 |

# - Water balance for the computer model of the borefields (see section 3.2). *ND* - No Data

In estimating the water balances for the GAB and the South Australian portion, a common assumption is that recharge approximates discharge (eg. Berry & Armstrong, 1995; Kinhill, 1997; Habermehl, 1998). The various components of discharge are reasonably well quantified, except for vertical leakage. Although no quantitative field studies of recharge are yet available, the recharge areas are known to be at full piezometric pressure, suggesting abundant, continuous recharge (Habermehl, 1998). When the above information is combined with some analytical techniques and observed artesian pressures, it is possible to derive a coarse estimate of total inflow. Thus the total outflow is assumed to be equivalent to this, and the vertical leakage is simply estimated as the difference, not any observed field processes. Hillier (1996) cautioned that the perceived steady-state condition may be a balance between outflow and transmission of water through the GAB aquifers rather recharge.

The total number of bores is still increasing, currently about 4,700 bores, although an increasing proportion of these are no longer free flowing and require pumping (Hillier, 1996; Habermehl, 1996a). The vast majority of the extracted water is wasted, estimated at 80% and up to 95% in some cases, due to uncontrolled bore flows and inefficient open earth drain distribution systems (Hillier, 1996; Habermehl, 1996b). The former Mines and Energy Department of South Australia commenced a bore rehabilitation and water conservation program in 1977, and presently only 10 to 12 of the present 170 bores in South Australia require further works (Sibenaler, 1996). The estimated water saving of this program is about 90 Ml/day (Sibenaler, 1996).

Figure 5 - GAB Bore Discharge and Bores Drilled Summary (Habermehl, pers. comm., 1998)



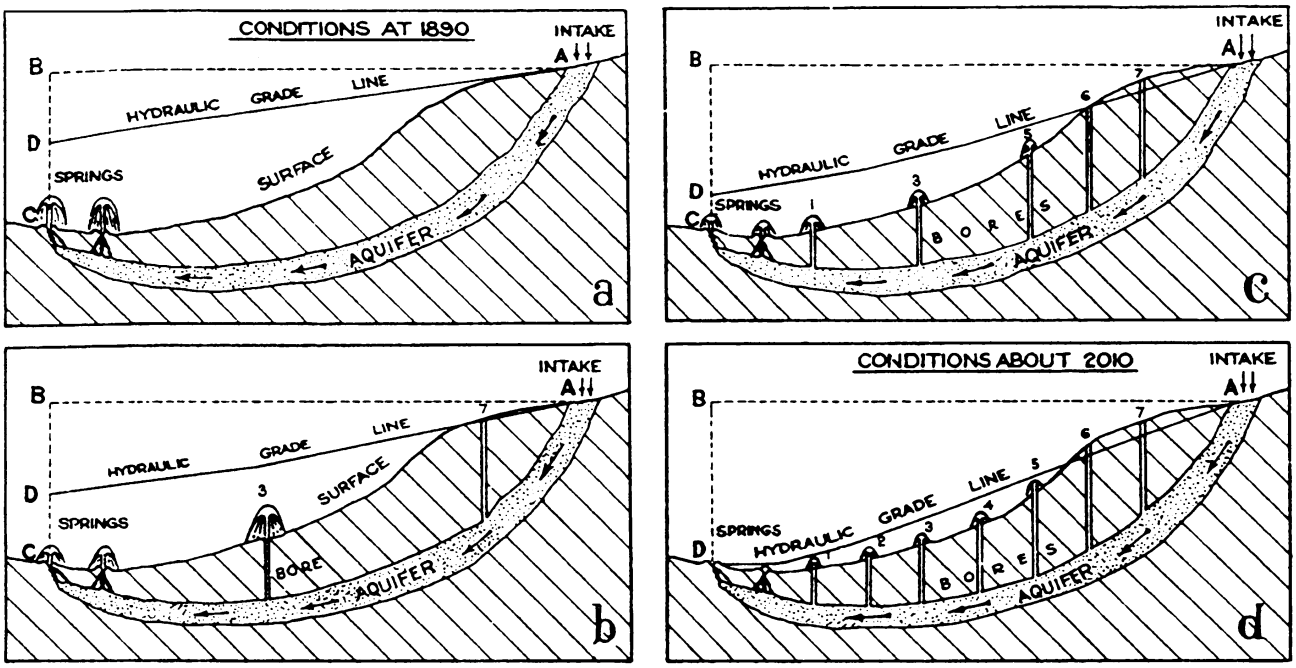

The Great Artesian Basin Bore Rehabilitation Program was introduced as an interstate working group in 1987 and water conservation measures are now being implemented across the entire GAB (Sampson, 1996; Hillier, 1996). This work includes rehabilitating bore headworks (such as corroded caps and valves), the use of polythene distribution piping, and float valve controlled tanks and trough systems (Habermehl, 1996a). In areas of rehabilitated bores the artesian pressure is beginning to increase, due to improved efficiency reducing demand and lowering flow rates (Hillier, 1996; Habermehl, 1996b).

## 7 PROSPECTS FOR IMPROVED WATER MANAGEMENT

It has long been recognised that continued overdevelopment of the GAB would lead to the extinction of flows at the mound springs. This scenario was first put forward by the Public Works Department in Queensland in 1954 when they assessed the sustainable supply of artesian water (DPW, 1954), and presented below in diagrammatically.

In words, it suggests that before European development of the GAB, artesian pressures and spring flows were relatively high. As bores were developed around the margin of the GAB and gradually in the centre, the overall artesian pressure begins to fall and spring flows decline, although initial artesian bore flows are reasonable. Finally, the GAB is developed with an extensive series of bores that each provide small relative flows, the artesian pressure of the GAB is exhausted and near ground level and there is no flow emanating from the mound springs. The current situation in South Australia is approaching the final stage of the above prediction - one made thirty years before the construction of the Olympic Dam water supply borefields.

Figure 6 - GAB Cross Section : Projection of Bores, Pressure and Spring Flow (DPW, 1954)




Despite the fundamental groundwater management principle outlined through Figure 8, there is often very little focus on management of the resources of the Great Artesian Basin to sustain minimum environmental flows at the springs across the GAB. Hillier (1996) highlighted these concerns, although he also stressed that economics and high value uses of GAB water, such as pastoralism, mining and other industrial projects, would be the over-riding management control.

There has been limited assessment of the effect of closing Borefield A on spring flow. These demonstrated that while Borefield B was still operating at full extraction capacity there would be no recovery of springs in the long term, with flows predicted to remain low or decrease from 1996 levels by up to 17% (Kinhill, 1995b; Berry & Armstrong, 1995). This can be considered to be due to the decrease in artesian pressure to the north due to Borefield B and no effective recovery mechanism for artesian pressure around Borefield A.

The regional contours of transmissivity and GAB aquifer thickness presented in Berry & Armstrong (1995) and Armstrong & Berry (1997) show that a further 100 to 200 km to the north and north-east of Borefield B, the GAB aquifer is relatively thick at about 300 to 400 m, is more permeable and reaches a transmissivity of 3,000 to 4,000 $m^2$/day. The aquifer thickness and transmissivity at Borefield A ranges from 10 to 25 m and 20 to 200 $m^2$/day, respectively. A borefield located in this new region would likely result in relatively lower drawdowns and occupy a smaller area compared to that from Borefield A. The potential for drawdown effects on the springs is therefore smaller than the current location of Borefield's A and B. A borefield located in this region would therefore be more sustainable for both spring flow and the long term life of the mine's water supply due to it's higher potential yield.

The prospect of a third borefield has been recognised with the current phase of expansion, and WMC will consider constructing it further into the GAB (Kinhill, 1997), as the properties just highlighted would suggest is appropriate. The data presented in Kinhill (1997) for water consumption at Olympic Dam suggest that water demand could range from 58 to 75 Ml/day for the full expansion to the 350,000 tpa of copper level, almost twice the currently approved extraction rate (Keane, 1997). This clearly suggests that there is a direct long-term need for a third borefield.

However, despite the more favourable hydrogeologic properties, a “Borefield C” would thus be at a further distance from the mine but the GAB aquifer is also deeper in this area. The overall costs of a new pipeline and deeper drilling could inhibit the timing and commitment by WMC to a new borefield. It is unclear whether Borefield A would be closed under this scenario.

To date there has been no public assessment of long term impacts of the borefields on the resources of the Great Artesian Basin the Lake Eyre region of South Australia. The modelling presented in Kinhill (1997) only examines a 20 year time frame. The Olympic Dam Project is estimated to operate for at least 50 to 100 years, and the borefields will be it’s only water supply. Indeed, it is arguable that the project would not be viable if the GAB borefields were not available. One pertinent point is that the spring flow projections in Kinhill (1997), at 20 years, are consistently declining as the impact of Borefield B dominates. There is a clear need for long-term modelling predictions to be made concerning impacts on spring flows, pastoral interests, and the time it would take for artesian pressures to recover in the region.

## 8 CONCLUSION

The Olympic Dam mine exemplifies the problems associated with establishing a large industrial operation in a region where water is a limiting resource. More significantly, this case reveals how water extraction can be a socially charged issue that can have significant long-term impacts on community relations with an industrial developer. Environmental Impact Statements are an important means of formally synthesizing scientific data on a region but on their own such documents cannot supplant appropriate management practices. Given the short-term nature of a mining operations and the long-term impacts of water extraction there is generally no inherent incentive for water conservation. This article has aimed to substantiate the problems which arise from an ad hoc approach to water management at a mine in an arid area. The data highlighted here leads us to reconsider the viability of such large operations in a water-limiting environment.

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