GEOTHERMAL RESOURCES OF THE GREAT ARTESIAN BASIN, AUSTRALIA

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INTRODUCTION

There is a little resemblance between world geothermal hot spots and the Australian landscape pictured in Figure 1. However, vast parts of the Australian continent have considerable reserves of geothermal energy stored in deep artesian groundwater basins in the form of warm groundwater.

Figure 1. *Typical landscape of inland Australia.*

Artesian groundwater was discovered in central and eastern inland Australia around 1880. Further extensive geological investigations and water-well information helped to outline the shape and size of a large confined groundwater system, now known as the Great Artesian Basin (GAB). The GAB extends across four Australian states underlying 22% of the Australian continent (Habermehl, 1980, 2001). Temperatures of the artesian groundwater (which is generally of a very good quality) range from 30º to 100º C at the well heads. As the groundwater is too hot for town water supply and for stock to drink, it needs to be cooled down before consumption. That is why cooling towers can be seen throughout the region. Some cooling towers are equipped with electric fans, in which the case electric power is spent to remove the thermal energy of the groundwater (Figure 2).

The efficiency of power generation from fluids of temperatures not exceeding 100º C is known to be low. However, there are some factors that may outweigh relatively low efficiency of electricity production from the GAB groundwater. One of such factors is a high cost of fossil-fuel electricity in remote locations of the GAB due to high transportation costs. Other factors, which one may need to consider, are the quality of the GAB groundwater and the flow rates of artesian wells.

Figure 2. *Cooling tower in the Borefield B of the Olympic Dam Mine, SA.*

In what follows we overview geothermal resources of the Great Artesian Basin and discuss prospective geothermal applications and their potential benefits for the region.

OVERVIEW OF THE RESOURCE

The Great Artesian Basin is a confined multi-layered groundwater system, which underlies 1.7 million km^2 of arid and semi-arid land across Queensland, New South Wales, South Australia and Northern Territory. Most artesian wells in the area tap the Cadna-owie-Hooray aquifer, the uppermost artesian aquifer of the multi-layered sequence. The aquifer consists of highly permeable sediments, mainly continental quartzose sandstones of horizontal permeability of around one darcy. (Detailed information on hydrogeology of the Cadna-owie - Hooray aquifer can be found in Habermehl, 1980 and Radke *et al.*, 2000.)

Groundwater Development

Somewhat 4700 artesian water-bores have been drilled in the Basin over the last 120 years, of which about 3100 remain flowing. Water-bores are up to 2000 m deep, although the average water-bore depth is about 500 m. Artesian flow rates from individual wells exceed 100 L/s, but the majority have smaller flow rates between 10 L/s to 50 L/s. The accumulated discharge of the GAB wells is about 1200 ML/day.

Groundwater in the Cadna-owie-Hooray aquifer is of good quality, containing between 500 mg/L to 1000 mg/L total dissolved solids. It is suitable for domestic, town water supply and stock use, though unsuitable for irrigation in most areas. The water is of the $Na\text{-}HCO_3\text{-}Cl$ type, and these ions
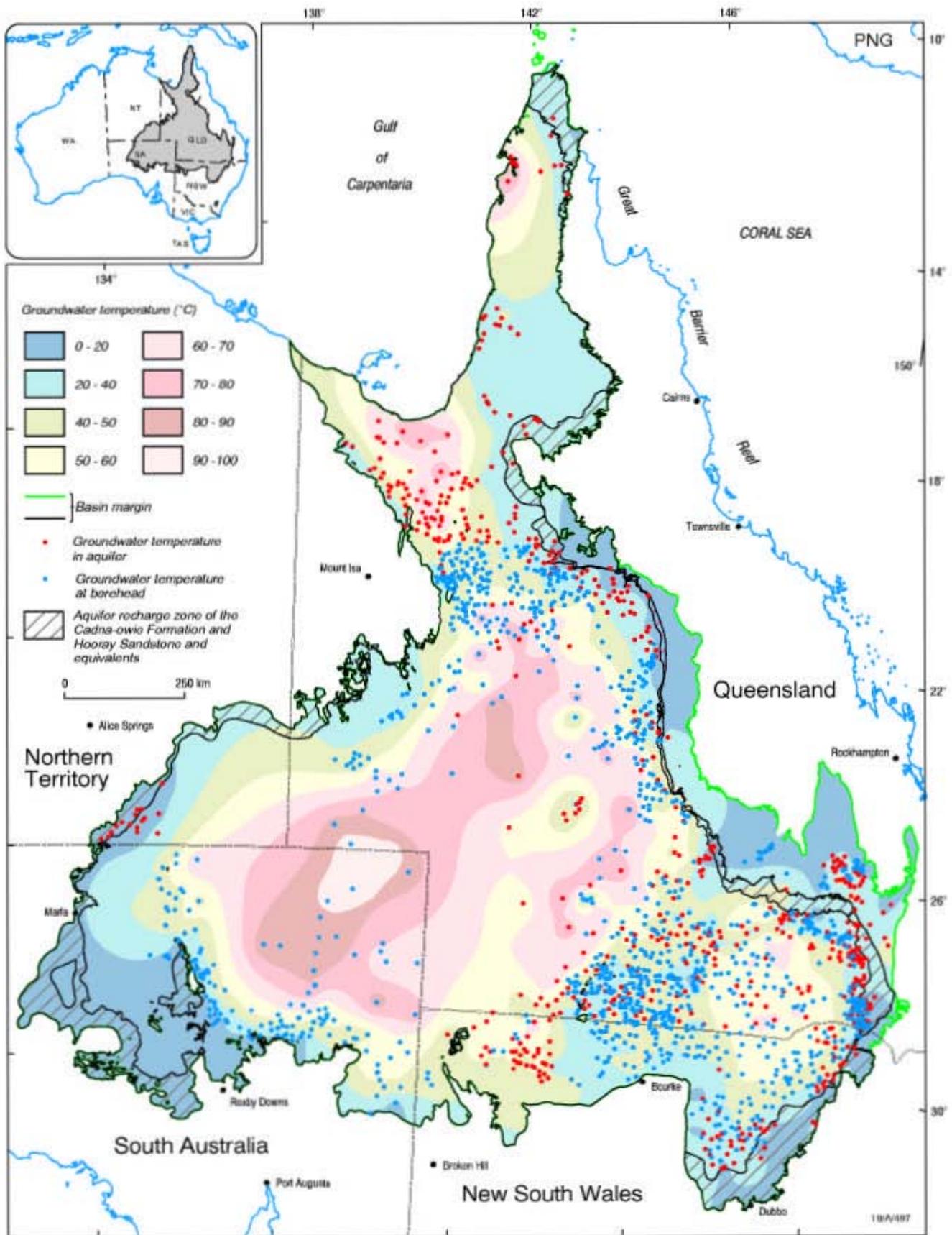
Figure 3.   *GAB groundwater temperatures (after Habermehl, 2001b).*

contribute more than 90% of the total ionic strength of solutes in the main Basin area. In the south-western part of the Basin the groundwater is characterized by Na-Cl-SO$_4$ type water (Habermehl, 1980, 2001a,b; Habermehl and Lau, 1997).

Groundwater Temperatures

Groundwater temperatures at the well heads range from 30° to 100° C. Spring temperatures range from 20° to 45°C, with the highest temperatures having been measured in the Dalhousie Springs group in northern South Australia. Figure 3 shows groundwater temperatures of the Cadna-owie - Hooray aquifer derived from measurements taken from 1880 water-bores. The density of observation data is high except for the central part of the Basin where the bore distribution is sparse.

The shallow parts of the Basin near the margins, in particular the eastern and western recharge margins and the areas basin-wards from these margins contain relatively cool water with temperatures not exceeding 40°C. The deepest parts of the Basin in northeastern South Australia and southwestern Queensland, the southwestern and central parts of the (geological) Eromanga Basin (the western and central parts of the hydrogeological Great Artesian Basin) have highest groundwater temperatures between 70° and 100°C (Habermehl, 2001a). For example, the Muloorina water bore has a groundwater temperature of 80°C (Figure 4). A ground-water temperature at Goyder Lagoon (SA) is 100°C (Figure 5). The Birdsville town bore has a temperature of 98° C. Near Quilpie (Qld) groundwater temperatures are between 70° and 80°C.

Figure 4. *80°C groundwater discharging from the Muloorina water-bore (SA).*

Geothermal Gradients

In general, a correlation exists between groundwater temperatures and aquifer depths. However, there are regions in the GAB, where warm groundwater is located at a relatively shallow depth of a few hundred meters. The map of geothermal gradients given in Figure 6 shows where warm groundwater comes close to the surface.

Figure 5. *Uncontrolled water-bore in Goyder Lagoon (SA) with a 100°C groundwater.*

Groundwater is heated by the heat flow attributed to the burial depth of aquifers and the heat produced in the earth crust by radio-active minerals, uranium and thorium (Torgersen, et al., 1992). In some parts of the Basin higher heat fluxes are attributed to the presence of young granite (Tony Hill, private communication). Thermal anomalies in some areas might be generated by vertical groundwater flow along geological faults. However, no thermal anomalies coincide with major faults, such as the Canaway Fault system (Habermehl and Lau, 1997).

The geothermal gradient surface of Figure 6 was developed by Tim Ransley from temperature log data of the GAB water-bores. The mean and maximum values of geothermal gradients for the Basin are 49.5 K/km and 120 K/km, respectively. In the most of the GAB geothermal gradients exceed the global average. Higher geothermal gradients occur in the south-central, northwestern and northern parts of the Basin. Some of these areas are underlain by igneous and metamorphic rocks. Highest geothermal gradients of 100 K/km and more are present in several isolated areas in the southwestern, south-central and northern areas of the GAB, and correlate with the location of hot springs (e.g., Dalhousie Springs group in northern South Australia). The central part of the Eromanga Basin and the Surat Basin are underlain by older sedimentary basins and have lower values of geothermal gradients. Geothermal gradients shown in Figure 6 are consistent with data given in previous works (cf. Polak and Horsfall, 1979; Cull and Conley, 1983; Pitt, 1986).

Effects of Temperature Variations

The effects of temperature variations on the hydrodynamics of the Great Artesian Basin have long been recognized, and attempts have been made to incorporate temperature-corrected heads into computer-based groundwater models. In some cases, however, such a correction may not be sufficient. According to Pestov (2000a), a head error due to the assumption of isothermal flow is not significant (less than 6%); whereas, an error in velocity calculations can be much
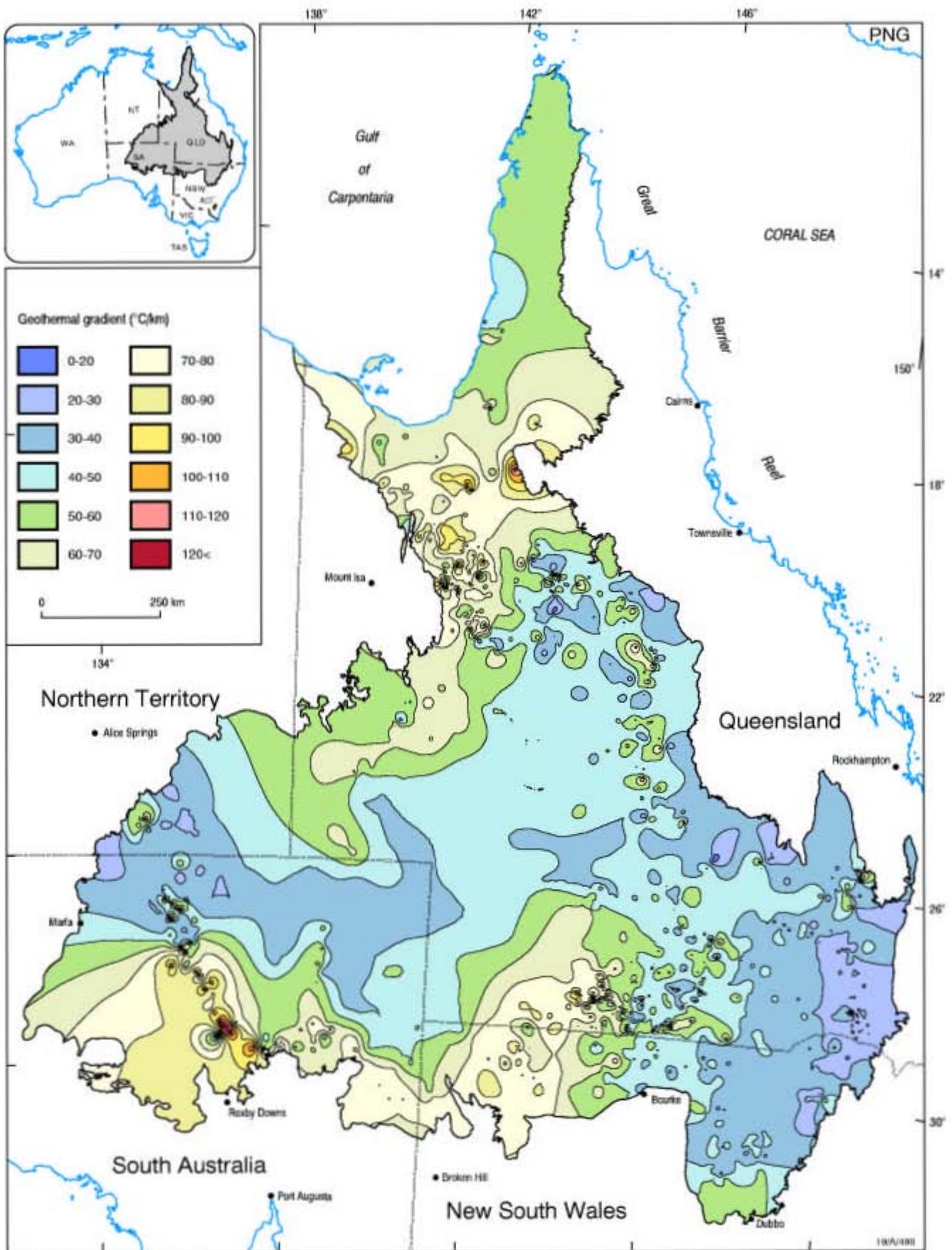
Figure 6.   GAB geothermal gradient (after Habermehl, 2001b).

higher. Pestov (2000a) has shown that dynamic viscosity of groundwater varies by a factor of four within a temperature range typical of the GAB. As groundwater velocity is inversely proportional to dynamic viscosity, viscosity variations of such a scale need to be incorporated into groundwater models. Both viscosity and density variations with temperature may result in completely different flow patterns compared to those predicted by isothermal groundwater models.

As demonstrated in computer experiments by Pestov (2000b), temperature variations similar to those found in the GAB are sufficient to trigger convective circulation in some parts of the Basin. There are six large-scale convective regions within the Cadna-owie-Hooray aquifer (see Figure 1 of Pestov, 2000b). The horizontal extent of convective regions is of the order of 100 km and more. The largest of convective regions, Eastern-Downs/Coonamble region, coincides with an important water management zone where most of the water-bores are located. In the Eastern-Downs/ Coonamble region the groundwater flow is likely to exist in the form of a giant convection cell with groundwater flowing in the opposite directions in the aquifer layers above and below the dividing aquitard, the Orallo formation (Pestov, 2000b). This conjecture is supported by field observations reported in Radke, et al. (2000). In other parts of the Basin, the groundwater flow is likely to form convection cells bounded to a single aquifer layer (Pestov, 2000b). Pestov (2000b) does not exclude the existence of thermal convection throughout the multiple aquifer sequence of the GAB.

Incorporating non-isothermal effects into groundwater models is important for sustainable management of geothermal resources in the GAB. Non-isothermal numerical models are discussed in Pestov (2000a, b). The importance of non-isothermal effects for transport of hydrocarbons and other chemicals in the GAB is discussed in Pestov (2000c).

PROSPECTS OF GEOTHERMAL DEVELOPMENT

The Great Artesian Basin has significant reserves of warm groundwater suitable for a variety of geothermal applications. Perspective applications include space heating, bathing, aquaculture, air conditioning and electric power generation. Heating requirements for the above applications are within the temperature range of the GAB groundwater.

Space Heating, Geothermal Bathing and Aquaculture

The GAB is largely located in tropical and sub-tropical Australia (see Figure 3). Annual average temperatures throughout most of the region range between 18° and 24°C. However, winter nights in inland areas of the GAB can be quite cool. The utilization of thermal energy of groundwater for space heating during winter will be an added benefit for inland Australia.

Bathing and aqua-culture are most promising geothermal applications at the low temperature end of the GAB groundwater. In spite of this, only one example of direct use is known in the area. In Moree, NSW a 40°C artesian groundwater is used in spa baths and swimming pools (Figure

7). With modern re-injection technologies, the GAB groundwater can be used at a significantly larger scale for both geothermal bathing and aquaculture. Benefits will include improved leaving standards of remote communities as well as new opportunities for tourism in the area. Geothermal bathing and a use of warm groundwater for seafood growing will make the area a more attractive tourist destination.

Figure 7. *Geothermal hot spa in Moree, NSW.*

Air Conditioning

Absorption refrigeration is another prospective geothermal application in the GAB. It works at the high temperature end of 80° C and above, "converting" geothermal heat into cold. This technology can be employed for comfort cooling in houses and other buildings in towns and individual homesteads during hot summer months. As it is not practical to transmit high-temperature water over large distances, geothermal technologies are at their most efficient when implemented close to the resource.

Very dry warm to hot climates predominate in the GAB area. In the central and western parts of the region maximum air temperatures often exceed 50°C. During summer months, the lion's share of electricity generated by diesel power stations is spent on air conditioning. Multiple benefits from an introduction of the absorption refrigeration technology in the region will include a reduction of green-house gas emission from diesel power stations that currently operate in the region.

Power Generation

Binary Rankine cycle geothermal plants successfully operated for a number of years in Mulka (SA) and in Birdsville (Qld). A small 20 kW facility at the Mulka cattle station in South Australia generated electricity for domestic needs using a 70°C to 100°C groundwater (Figure 8). Since the plant was equipped with an old type generator containing a Freon-based working fluid, it had to be shut down in the mid 1990s (Cam Douglas, personal communication; also see CADDET link below). The 150 KW geothermal plant in Birdsville was shut down in 1996 for the same reason. In 1999-2000 the Birdsville plant has been re-equipped with a hydrocarbon-based working fluid (isopentane). It is currently

Figure 8.   *Geothermal plant at the Mulka Cattle station, SA.*

capable of generating 120 KW electricity from a 98°C groundwater (Bob Collins, personal communication; also see link to the Birdsville geothermal plant web page below). As demonstrated by the Mulka and Birdsville examples, geothermal resources of the GAB are capable of supporting electric power generation at a considerable scale.

The efficiency of power generation from low-enthalpy fluids largely depends on the resource temperature (Rafferty, 2000). Lower groundwater temperatures will require higher heat input due to lower efficiency of the plant. Although the groundwater temperatures in the GAB do not exceed 100°C, the flow rates from the GAB artesian wells are generally very good.

We have calculated the flow rates, which will be required to support a 100 kW binary (Rankine cycle) plant at different resource temperatures. The results of our calculations are shown in Table 1. Note that the highest flow rate of 3383 m/day is still within the range of the flow rates of the GAB wells. Our calculations are based on the net plant efficiency for different temperature as given in Figure 2 of (Rafferty, 2000).

Table 1.   **Geothermal Flow Rates for a 100-KW Binary Plant at Different Resource Temperatures**

T (deg C)	Efficiency (%)	Heat Input (kJ/h)	Flow Rate (cubic meter/day)
82	5.5	1818	3383
88	6.25	1600	1984
93	6.8	1471	1368
99	7.25	1379	1026
104	7.5	1333	827

The Kalina technology makes a better use of the heat input through improved efficiency compared to that of the binary plant. According to Spinks (1994) the efficiency of the Kalina cycle could be 10% to 25% higher than that of the Rankine cycle. In addition, Kalina plant's installed cost per kilowatt could be substantially lower (e.g., 40% lower) compared to that of the binary plant (Spinks, 1994).

It should be noted that the geothermal plant efficiency is considered to be low when compared to fossil-fuel power generation not to other renewable energy sources. It is very likely though that the cost of electricity generated from local geothermal resources will be competitive with the cost of fossil-fuel and power-grid electricity due to high transportation expenses for remote locations of the GAB. "Off-grid" remote communities will particularly benefit from a reliable electricity supply of small easy-to-operate geothermal plants. Binary plants of 100 kW capacity or less will be suitable for small-scale applications such as electricity supply to townships, homesteads and cattle stations. Note that about half of urban centers in the GAB area have a population of less than 2,500 (Habermehl, 1980).

CONCLUSIONS

Geothermal energy of the artesian groundwater in the Great Artesian Basin is a valuable natural resource suitable for a variety of useful applications. Prospective applications include direct-use applications, such as space heating, bathing, aquaculture and air-conditioning, as well as electric power generation.

Bathing and aquaculture are most promising geothermal applications at the low temperature end of the GAB groundwater (30° - 40°C). Absorption refrigeration, which works at the high temperature end of 80°C and above, is another prospective geothermal application for the hot climate of the region.

Although the groundwater temperatures in the GAB do not exceed 100°C, the flow rates from the artesian wells are generally very good. Our calculations show that the flow rates from the GAB wells are capable of supporting heat inputs required for electric power production (see Table 1).

With modern re-injection and numerical simulation technologies thermal energy of the artesian groundwater of the GAB aquifers can be utilized in a sustainable way to the benefits of remote communities. "Off-grid" communities will particularly benefit from a reliable electricity supply of small easy-to-operate binary plants. The Kalina technology has a potential to improve efficiency of power production from the GAB groundwater.

The cost of electricity generated from local geothermal resources is not expected to be high compared to the costs of other types of electricity including fossil-fuel and power-grid electricity. Reduction of greenhouse gas emission will be an added benefit of geothermal developments in the Great Artesian Basin.

INTERNET LINKS
CADDET, Australia: www.isr.gov.au/resources/netenergy/domestic/caddet/caddet-home/index.html

Birdsville geothermal plant: www.env.qld.gov.au/sustainable_energy/qseif/projects/birdsville_geothermal.htm

REFERENCES
Cull, J. P. and D. Conley, 1983. "Geothermal Gradients and Heat Flow in Australian Sedimentary Basins." *BMR J. Aust. Geol. Geophys.*, 8, 329 - 337.

Habermehl, M. A., 1980. "The Great Artesian Basin, Australia." *BMR J. Aust. Geol. Geophys.*, 5, 9-38.

Habermehl, M. A.,2001a "Hydrogeology and Environmental Geology of the Great Artesian Basin, Australia." In: V.A. Gostin (ed) *Gondwana to Greenhouse - Australian Environmental Geoscience.* Geological Society of Australia Inc., Special Publication 21: 127-143, 344-346.

Habermehl, M. A., 2001b. *Wire-Line Logged Waterbores in the Great Artesian Basin, Australia - Digital Data of Logs and Waterbore Data Acquired by AGSO.* Bureau of Rural Sciences publication, Canberra, Australia; also: Australian Geological Survey Organisation, Bulletin 245.

Habermehl, M. A. and J. E. Lau, 1997. Hydrogeology of the Great Artesian Basin, Australia (Map at scale 1 : 2 500 000), Australian Geological Survey Organisation, Canberra.

Pestov, I., 2000a. "Modeling Non-Isothermal Flows in Porous Media: A Case Study Using An Example of the Great Artesian Basin, Australia." In: *New Methods in Applied and Computational Mathematics* (R. Melnik, S. Oliveira and D. Stewart, eds.), Center for Mathematics and its Applications, Australian National University, Australia, 59-65.

Pestov, I., 2000b. "Thermal Convection in the Great Artesian Basin, Australia." *Water Resources Management*, 14, 391-403.

Pestov, I., 2000c. "Thermal Convection and Mass Transfer in Sedimentary Basins: Implications for Management." *Proc. Int. Hydrology and Water Resources Symposium*, Institution of Engineers, Australia, 980-984.

Pitt, G. M., 1986. " Geothermal Gradients, Geothermal Histories and the Timing of Thermal Naturation in the Eromanga-Cooper Basins." In: Gravestock, D.I., Moore, P.S. and Pitt, G.M. (eds) *Contributions to the Geology and Hydrocarbon Potential of the Eromanga Basin.* Geological Society of Australia Inc. Special Publication No. 12, 323-351.

Polak, E. J. and C. L. Horsfall, 1979. "Geothermal Gradients in the Great Artesian Basin, Australia. " *Bull. Aust. Soc. Explor. Geophys.*, 10, 144-148.

Radke, B. M.; Ferguson, J.; Cresswell, R. G.; Ransley, T. R. and M. A. Habermehl, 2000. *The Hydrochemistry and Applied Hydrodynamics of the Cadna-owie-Hooray Aquifer, Great Artesian Basin, Australia.* Bureau of Rural Sciences publication, Canberra, Australia.

Rafferty, K., 2000. " Geothermal Power Generation: A Primer on Low-Temperature, Small-Scale Applications." Geo-Heat Center electronic publication.

Spinks, A. H., 1994. "The Commercial Development of the Kalina Cycle and A 30-Megawatt Design for Wairakei." *Proc. 16th NZ Geotherm. Workshop*, 269-274.

Torgersen, T.; Habermehl, M. A. and W. B. Clarke, 1992. Crustal Helium Fluxes and Heat Flow in the Great Artesian Basin, Australia." *Chemical Geology (Isotope Geoscience Section)*, 102, 139-152.