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INVESTIGATIONS OF THE GEOLOGY AND HYDROLOGY OF THE GREAT ARTESIAN BASIN 1878-1980

by

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ABSTRACT

A review is given of the significant literature dealing with the groundwater development and investigations of the geology and hydrology of the Great Artesian Basin. This compilation was prepared as part of the hydrogeological study of the Great Artesian Basin, carried out by BMR from 1971 to 1980.

INTRODUCTION

The Great Artesian Basin (Fig. 1) is a confined groundwater basin comprising aquifers and confining beds throughout the Middle Triassic to Late Cretaceous sedimentary sequence in the constituent sedimentary Bowen, Galilee, Eromanga, Surat, and Carpentaria Basins (Habermehl, 1980a).

The Bureau of Mineral Resources, Geology and Geophysics (BMR) carried out a basin-wide hydrogeological study of the Great Artesian Basin from 1971 to 1980 (Habermehl, 1980a). The objectives of the study were to review the geological and hydrological data of the multi-layered confined aquifer system of the Great Artesian Basin and to develop and apply a mathematical, computer-based model to simulate the groundwater hydrodynamics.

An outline of the hydrogeology of the Basin is given in Habermehl (1980a). The digital model 'GABHYD', based on the finite difference approach, is described by Seidel (1978 a, b, 1980 a, b). Results of the digital computer model predictions of the future hydraulic behaviour of the basin following management interventions, which can be used for assessment, planning, and management purposes on a regional scale of the Basin's artesian groundwater resources, are reported in Habermehl & Seidel (1979) and Seidel (1980a).

A review is made here of the most significant literature dealing with the history of groundwater development and investigations of the geology and hydrology of the Great Artesian Basin. This review is not based on a complete bibliography on the Great Artesian Basin, and more recent publications on the geology of the Basin are not recorded as these can readily be found in recent descriptions of the geology of the constituent sedimentary basins: the Eromanga, Surat, and Carpentaria Basins, and small upper parts of the Bowen and Galilee Basins.

Various names and meanings have been applied to the Great Artesian Basin since the basin was discovered around 1880. David (1893) discussed the 'artesian basin of New South Wales and Queensland', and refers to 'the artesian basin of Australia', but does not use these terms as formal names; neither does Jack in several of his papers, though he also uses the term 'the artesian basin' (Jack, 1897). Pittman (1901) discussed the term 'artesian basin' and its application to 'the great Artesian basin of Queensland, New South Wales, and South Australia' and stated that 'what is generally termed the New South Wales Artesian Basin ... is in reality the south-eastern portion of the Great Australian Artesian Basin'. He showed the extent of the 'Great Artesian Basin' on a map of Australia.

The inconsistent use of the terms 'Great Artesian Basin' and 'Great Australian Artesian Basin', as well as 'Great Australian Basin', 'Artesian Basin' and 'Great Basin' was to continue for many decades. Pittman (1907, 1914, 1915, 1917), Du Toit (1917), Jack (1923, 1930), and Kenny (1934) generally use the term 'Great Australian Artesian Basin'. In Reports of the Interstate Conferences on Artesian Water (1913, 1914, 1922, 1925, 1929) the terms 'Great Australian Artesian Basin' and 'Great Artesian Basin' are frequently used, though the term 'Great Australian Basin' seems to dominate. Whitehouse (1930) used 'Great Artesian Basin', Ward (1946) used 'Great Australian Artesian Basin', 'Great Australian Basin' and 'Great Artesian Basin', and David (1950) refers to the term 'Great Australian Basin' but used 'Great Artesian Basin' almost exclusively. The Queensland Government Reports (1945, 1954) used the term 'Great Artesian Basin' throughout, and so did Whitehouse (1954), though the title of his report (and that of Ogilvie, 1954) shows 'Great Australian Artesian Basin'.

Throughout the 1950s and 1960s, authors used the term 'Great Artesian Basin' (Hind & Helby, 1969; Parkin, 1965; Wopfner & others, 1970; and in publications by BMR, and the Geological Surveys of Queensland, New South Wales, and South Australia) to describe geological, structural, and hydrological aspects of the area. Vine (1969) sought to restrict the usage of the term 'Great Artesian Basin' to the hydrological basin and separate it from any geological meaning. Bourke & others (1974) and Hawke & others (1975) defined the term 'Great Australian Basin' for a composite structural basin which represents a group of major Jurassic-Cretaceous epi-cratonic sedimentary basins including the Carpentaria, Eromanga, and Surat Basins. Habermehl (1980a) defined the Great Artesian Basin as shown in the first paragraph of this chapter.

Fig. 1 Location and extent of the Great Artesian Basin, Australia

GROUNDWATER DEVELOPMENT AND EARLY INVESTIGATIONS, 1878 to 1912

Early exploration

Land settlement and pastoral activity in Australia progressed westward during the nineteenth century and caused an increasing demand in the arid zone for reliable and permanent water supplies.

Rawlinson (1878) and Russell (1880, 1889) suggested that meteoric water could infiltrate the western slopes of the Great Dividing Range to form a potential source of groundwater which could be tapped by wells in the interior.

Tate (1879, 1882) developed the idea that artesian water could be found across most of central and eastern inland Australia. He based his theory on the occurrence of artesian springs (mound springs) around the southern and western shores of Lake Eyre, and correlated these 'hot mineral' springs with the distribution of Jurassic rocks. He identified these springs as natural artesian wells 'as they flow to the surface of an open level plain in an arid climate'. Tate stated that other writers attributed these springs to a volcanic origin, because of the crater-like mounds of 'sinter' which had been deposited.

The first water wells

The first flowing artesian well tapping a pressure aquifer in the Great Artesian Basin was constructed about 170 km southwest of Bourke in New South Wales in 1878 (Water Resources Commission - New South Wales Registered Number 4266 - WRC-NSW RN4266, 53 m - 175 ft) - note also the description in Williamson (1966). In South Australia, a successful artesian well was sunk in 1881, near Anna Creek, west of Lake Eyre, and, as in the case of the New South Wales well, in the vicinity of mound springs. It was soon followed by wells being drilled along the Birdsville Track. In Queensland several shallow non-flowing artesian wells (about 91 m - 300 ft depth) tapping the Winton aquifer were drilled near Winton in about 1882, and a shallow artesian well near Julia Creek in 1884 (Water Resources Commission - Queensland Registered Number 3507 - WRC-Qld RN3507, 61 m - 200 ft).

Jack (1898) suggested in 1881 that a large synclinal trough existed in western Queensland and that, in the pervious beds of this trough, water accumulated from the Dividing Ranges, and so formed conditions favourable for artesian wells. If artesian water supplies could be tapped it would alleviate some of the problems that existed in an area that had great opportunities for pastoral purposes. The climatic regime of periods with good rainfall and long droughts is the critical factor controlling both the vegetation i.e. the feed for stock, and available surface water on which both the human population and stock are dependent. The search for artesian water and the associated basin was at first spasmodic, but soon direct investigations were undertaken.

In Queensland the Water Supply Department, and in New South Wales the Water Conservation and Irrigation Branch were set up to provide adequate water supplies, and undertake investigations and control drilling undertaken by government authorities. The New South Wales authority was established following a Royal Commission on Aspects of Water Conservation. Severe droughts in the mid-1880s led the Queensland Government to direct R.L. Jack (Government Geologist) and J.B. Henderson (Hydraulic Engineer) to investigate the existence of artesian water in the State, and advise the Government on the prospects of drilling for artesian water in western Queensland.

A geological survey was carried out, and the conclusion reached in 1885 (Jack, 1895a) that the whole of the western interior offered a promise of artesian water. Immediate drilling was recommended, and J.B. Henderson selected Blackall for the first wellsite, as this township was in a desperate position with regard to its town water supply. However, drilling difficulties delayed the completion of the Blackall well (WRC-Qld RN317, 507 m - 1663 ft), which had been commenced in 1885, until 1888 (Queensland, 1888). In the meantime (1886) other deep successful artesian wells had been drilled and completed in Queensland near Cunnamulla (WRC-Qld RN4514, 393 m - 1290 ft) and Barcaldine (WRC-Qld RN312, 211 m - 691 ft) in 1887, followed by other deep artesian wells near Barcaldine (WRC-Qld RN278, 298 m - 978 ft) and Tambo (WRC-Qld RN398, 305 m - 1002 ft) in 1888 (see also the list in Queensland Government, 1954, p. 23). In 1888 wells were completed in New South Wales west of Bourke and south of Yantabulla (WRC-NSW RN4282, 327 m - 1073 ft, WRC-NSW RN4137, 250 m - 820 ft and WRC-NSW RN4391, 279 m - 916 ft), and many more were commenced. Drilling for stock, domestic, and town water supplies expanded rapidly from then on, and investigations commenced to delineate the limits of the Basin.

Early geological exploration

Geological mapping and the information from boreholes enabled Wilkinson (1882, 1887), Jack (1895b, 1897, 1898) and David (1891, 1893) to establish that the Lower Cretaceous sedimentary sequence contained the main aquifers. Jack (1895 a, b) reported the results of geological mapping during 1894 of intake bed along the Great Dividing Range from the Queensland-New South Wales border near Goondiwindi northwest of the Hughenden area, and he identified the sandstones which represent the main aquifers. Pittman (1895a, b, 1896 a, b, 1897) commenced systematic geological investigations of the Great Artesian Basin in New South Wales, and progressively the Basin's outline and size became better known as mapping and drilling continued.

Geological mapping continued along the northern margins by Jack (1896) and Maitland & Jack (1898), along the northwestern margin by Jack (1896) and Cameron (1901), in the southern part by Brown (1892, 1894), and in the southeastern part by Pittman (1895 a, b, 1896 a, b). As a result, the Basin was fairly well defined before the end of the nineteenth century.

The investigation of hydrological features also continued, and included a preliminary hydraulic survey in Queensland in 1896 (Queensland, 1896) and the collection of details about artesian wells and springs (Annual Report of the Hydraulic Engineer on Water Supply (Queensland)). Unsuccessful attempts were made to bring the drilling and completion of wells, and the usage of artesian water under government control in Queensland in 1891 and 1893 (Queensland Government, 1954).

Early hydraulic theory

The Great Artesian basin had been explained and was accepted by many workers around the end of the nineteenth century as a classic artesian basin, where meteoric water infiltrates outcropping aquifers, and moves underground towards the lowest outlets. The principle of hydraulic pressure of the water in the confined aquifers was also understood, and pressure measurements obtained during field surveys confirmed the theory, though some controversy remained as to whether the pressure head was of hydraulic or hydrostatic origin, i.e. whether an outlet existed in the Basin or not (David, 1893; Jack, 1897; Maitland, 1897; Pittman, 1901). The difference in hydrostatic or hydrodynamic conditions of the Basin was important, as it would assist in predicting the results of the already decreasing flow and pressure of artesian wells. The hydrodynamic theory was most commonly accepted, and as the calculated recharge and the natural discharge from springs were found not to be equal, outlets for the Basin were proposed and presumed to occur in the Gulf of Carpentaria and (the main one) in the Great Australian Bight.

These interpretations about the origin and movement of the artesian water were all made before 1900, and were attacked by Gregory (1901, 1906, 1911). Gregory believed in a connate and plutonic origin of the water in the Great Artesian Basin, where movement was the result of heat, gas and rock pressure in the Earth's crust, rather than a meteoric origin and movement under hydraulic conditions. Gregory's explanation was disturbing, because it could mean that the Basin's water resources had a limited life and could eventually become exhausted. The flow and pressure of the artesian wells generally decreased soon after completion and continued to decrease with time, adding weight to Gregory's theory.

Gregory's (1901, 1906, 1911, 1914) theories were skilfully refuted by defendants of the meteoric and hydraulic theory, notably Knibbs (1903), Pittman (1907, 1914, 1915), and Pittman & David (1903). Gregory was supported by Symmonds (1912) and Du Toit (1917), who subscribed to most or all of his views, and the controversy continued, with neither side being able to convince the other. However the theory of the meteoric origin, and the movement of the water under hydraulic conditions from the eastern, elevated recharge areas which had earlier been delineated by Jack, Maitland, and Pittman, gained ground and became generally accepted. The controversy inspired increased research into the character of the Basin and a good outline of the knowledge about the Basin during the period in the early years of this century is given in the papers by Pittman published in 1914 and 1915; Pittman (1914) contains an extensive <u>bibliography on artesian water in Australia</u>.

<u>State government legislation and control</u>

Diminishing flows and pressures in artesian wells alarmed well owners. Ultimately State governments became involved, their attention having already been drawn to the wastage of water from many of the privately drilled artesian wells.

In Queensland, an attempt was made in 1891 to introduce government control, but the legislation was rejected and not passed until 1910; control in New South Wales was attempted in Acts introduced in 1894, 1897, and 1906 but was not achieved until 1912. Once legislation became effective, control was enforced and systematic measurements made by existing and newly formed water authorities in Queensland and New South Wales; in South Australia no real control was exercised until 1976. Information about artesian wells, especially concerning the diminishing flows, had already been gathered intermittently, but was incomplete; only after legislation had been passed did official collection of data begin. The new legislation provided for wells to be licensed, and required that all relevant details be submitted to the State water authority, and the casing and headworks completed according to prescribed standards. Problems related to the diminishing and ceasing flows, corrosion of well casing, extent of the Basin, and the origin and movement of the artesian water required an explanation. A proposal was made by the New South Wales government in 1908 to the other Australian states to 'form a consultative Board consisting of representatives from the various States, to take into consideration the question of whether the Artesian Water Supply of Australia was in danger of being seriously diminished, and, if necessary to advise as to the best means of combating the contingency'. No such board was established, but in 1911 the matter was revived, and in 1912 the First Interstate Conference on Artesian Water was held in Sydney, with representatives attending from all mainland States.

Though other artesian basins in Australia were also discussed, the emphasis was on the Great Artesian Basin, not only during this conference, but also during the following Interstate Conference on Artesian Water at Brisbane 1914, Adelaide 1921, Perth, 1924, and Sydney 1928. No further meetings were held until 1939, when an Interstate Conference on Water Conservation and Irrigation was held in Sydney and discussed most aspects of ground and surface water. Clark (1979) reviews the groundwater law and administration in Australia, the first stages of which received a great impetus from the early exploration of the Great Artesian Basin.

INTERSTATE CONFERENCES ON ARTESIAN WATER, 1912 TO 1928 AND 1939

Reports covering the 1912 to 1928 Interstate Conferences on Artesian Water describe the submissions and deliberations, and contain much information (in the form of maps and tables) about the Great Artesian Basin, its wells and springs.

The reports of the First and Second Conferences are mainly concerned with the collection of information and the verbal presentations by the (State) delegates and the people interviewed, mainly pastoralists, drillers, engineers, chemists, and administrators who could supply evidence about the artesian basin. The reports of the Third, Fourth, and Fifth Conferences only record submissions by the State representatives who presented detailed data about artesian basins (mainly the Great Artesian Basin), the wells tapping these basins, and the progress in local (State) investigations. The accompanying geological and potentiometric maps, tables with well data, and other information show the improvement of knowledge about the Basin during the years. Conference delegates were all State geologists and hydraulic engineers; a representative from the Commonwealth attended the Fourth and Fifth Conferences.

First Interstate Conference on Artesian Water, 1912

The First Interstate Conference on Artesian Water (ICAW) in Sydney in 1912 was concerned with the limits of the Great Artesian Basin, its intake areas, natural outlets, and the origin and movement of water in the Basin. The problems of diminishing pressure and flow of wells, the corrosion of well casings, and other related matters were also covered.

Resolutions carried by the conference dealt with uniform nomenclature, collection and publication of geological, hydrological, and chemical data, proposals for the determination of boundaries of artesian basins, hydrographic, hydraulic, and meteorological investigations, the problems related to the decrease of flows from wells, and the leakage and corrosion of casings. It was recommended that the State authorities should control the number of wells to be drilled, supervise the drilling, and restrict the amount of flow from wells. Also, water should not be used for irrigation (mainly because of the already diminishing flow), as town water supplies and pastoral uses were of paramount importance. An interstate board of investigation should be established, to meet annually, and discuss, correlate, and record data. An urgent recommendation asked for uniform legislation in all States, following the New South Wales and Queensland Acts, to control and license all wells, supervise drilling methods, and periodically examine all wells.

In addition to the many maps, tables, diagrams, and photographs in the conference Report (ICAW, 1913) which deal with the extent of artesian basins in Australia, locations of wells, geology, potentials, temperatures, flowrates, isopachs of aquifers, decrease in flow and pressure of wells, areas where diminishing flow and/or corrosion occurred, cross-sections between wells, corroded casing, mound springs, headworks of wells, chemical analyses of water from wells, etc., the Report includes a comprehensive bibliography relating to groundwater in Australia prior to 1912.

The conference delegates went on an inspection tour in part of the Great Artesian Basin in New South Wales, near Coonamble, taking evidence on the corrosion of well casings in that area, and to the region between Walgett and Moree to inspect cooperatively exploited artesian water wells and their distribution systems (open earth drains).

The Report shows that the information about the Basin had increased substantially, and that many of the earlier assumptions and theories, though generally correct, could now be explained and verified with recorded data. The limits, and to a large extent the basic geology of the Basin, were understood, as were the hydraulic principles and the effects of the development of the groundwater resource. A major achievement of the First Conference was the recognition of the type of data required to prepare an improved analysis of the hydrogeology and the hydrodynamics of the Basin and the recommendation to collect these data, which was followed in some States by active fieldwork and systematic measurements.

Second Interstate Conference on Artesian Water, 1914

The Second Interstate Conference on Artesian Water was held in Brisbane in 1914. Geologists and hydraulic engineers from all the Australian mainland State governments were present and discussed the source of the artesian water, the lower limit of water-bearing strata, the diminution of supply from the wells, the pressure testing of wells and other data collected, drilling methods and the conservation of water and prevention of wastage, corrosion, the origin of gasses in the artesian water, and the results of continuing investigations in the different States. The conference delegates undertook an extensive tour through a large part of the Great Artesian Basin in Queensland to collect information from farmers and drillers and inspect recharge areas and wells. The visit to the Basin and the interviews with people concerned with drilling and utilisation of groundwater, were made on the request of the Queensland Government which was experiencing fierce opposition from landholders about its water legislation which had been operative since 1911. Many well owners objected to the legislation, which specified methods of well completion, control of well discharges, and the periodical pressure testing of private wells by government authorities. Misunderstanding or a lack of knowledge about the basic principles of an artesian basin appeared to be common, and decreases in well discharge were often attributed to pressure measurement activities. Reluctance to meet the most basic well design requirements also occurred. Hence, largely as a result of these misunderstandings, the regulations which were prepared to assist the community in utilising the artesian water supply in the best possible manner, were strongly condemned and opposed.

The Second Conference did much to clarify matters concerning the source of the water, its origin, and the diminishing discharges, to explain and recommend improved well drilling and completion techniques, and to discard popular, but incorrect theories among people concerned with artesian water. Recommendations of the First Conference were reaffirmed; other recommendations included the need for further surveying of the Basin margins, especially the completion of geological work on the eastern and northwestern parts (E.C. Saint-Smith reported during the conference a redefinition of the intake beds in southeastern Queensland which consisted, according to him, of Triassic-Jurassic beds), and drilling by the State governments of some deep wells in the deep parts of the Basin to gather hydrogeological information. The investigation of many other characteristics of the aquifers and artesian water as well as specific problems related to artesian wells were recommended. Maps, sections, and tables with large amounts of data about periodical measurements on wells and other information accompany the Report (ICAW, 1914) of this Conference. The increased data about the Basin were collected in a systematic manner, and were of great value to the combined attempts of the States to improve the knowledge about the Great Artesian Basin.

Third Interstate Conference on Artesian Water, 1921

The Third Interstate Conference on Artesian Water was held in Adelaide in 1921, and not as planned in 1916, due to the interference of World War I. Geologists and hydraulic engineers of the five mainland States attended, and presented contributions on the progress of the work carried out in the Basin since 1914, the time of the previous conference. Delegates also inspected mound springs southwest of Lake Eyre, which form natural discharge points of the Basin.

Progress reports included a better definition of the western limits of the Basin, parts of which were recognised as potential recharge areas, and were verified by potentiometric and chemical data. A considerable amount of data have been collected through systematic measurement of pressure, flow, temperature, and chemistry. The decrease in flow from existing wells continued, and levels continued to fall, but it had been shown that better well completion techniques, such as cementing of the casing, and the partial closing of fully flowing wells of which not all the water was required, had a beneficial effect on the decrease in flow and pressure. Investigation of the corrosion of the iron and steel casing in use in the Basin wells continued, and though it was known that nickel-steel would resist corrosion, its use was not yet economically viable. Temperature gradients had been calculated, and the results ruled out any possible plutonic explanation for the source of water as suggested by some earlier authors. A detailed description was given of the deepest water-well (WRC-Qld RN3489, Springleigh) in the basin, completed 75 km WSW of Blackall, Queensland in 1921 at a total depth of 2136 m (7009 ft).

Appended to the Conference Report (ICAW, 1922) are tables with detailed data about wells, meteorological information, chemical analyses, etc., maps, diagrams, and a bibliography on the Basin and artesian water in South Australia. The maps and diagrams deal with geological and hydrological aspects, and include cross-sections, potentiometric maps, time-pressure (recovery), temperature, flow and potential diagrams, and many other data.

The Report shows that valuable data continued to be collected and analysed, which despite restrictions led to some remarkable results. Lack of knowledge of subsurface geology led to all measurements being treated as belonging to a single aquifer rather than several aquifers.

Recommendations by the Third Conference included the search for mound springs and measurement of their discharges, further collection of hydrodynamic and other data on wells, the interference effect of wells, and various other items, many of which were repeated from previous conferences.

Fourth Interstate Conference on Artesian Water, 1924

The Fourth Interstate Conference on Artesian Water was held in Perth in 1924. Geologists from New South Wales, Victoria, South Australia, Western Australia, and the Commonwealth attended. Results on the investigations carried out in the States and the Northern Territory were presented and discussed. A field trip was also included in this Conference.

The Conference Report (ICAW, 1925) includes a summary of the previous conferences and contains the progress reports of investigations undertaken by each of the States. These State reports consisted of statements about the continuing diminution of flows and heads, aquifer characteristics, and corrosion. A paper by Jack (1923) is included in the Conference Report, and records the variation in chemical composition of water from mound springs and wells in South Australia. The discussion is supplemented by maps showing chemical and potentiometric data.

Jack's work led to definite conclusions about the western and eastern intake areas, and the direction of movement of the water in that part of the Basin. Water from the eastern sources was shown to be rich in carbonate, and water originating in the western area is rich in sulphate. A southeast-trending zone of mixing is located between Dalhousie Springs and Lake Eyre. Mound springs were assumed to be the only natural outlets of the water, and one quarter of the discharge was estimated to have been derived from the western intake. Investigations and well development had also revealed the existence of a perched sub-artesian basin in the northeastern part of South Australia and parts of New South Wales, i.e. the existence of significant confined aquifers not related to the main Jurassic aquifer. A revision of the well data became necessary with the recognition of the existence of several confined aquifers. In relation to this the recommendation from the Third Conference was repeated, for a uniform classification and nomenclature of formations occurring in different States; it was also recommended that a joint examination should be made of parts of the margins of the Basin.

Appendixes to the Conference Report (ICAW, 1925) contain data, including the annual rate of decrease in flows and water levels, of wells in the Northern Territory, New South Wales, and South Australia. Maps show potentials, springs, wells, and outline of the Basin.

Fifth Interstate Conference on Artesian Water, 1928

The Fifth Interstate Conference on Artesian Water was held in Sydney in 1928, and was attended by representatives of the four eastern States and the Northern Territory. New information on the Basins, gathered since the previous meeting, was presented, and a visit was made to parts of the Basin in northwestern New South Wales and southern Queensland. Mound springs and flowing wells were also inspected between Hungerford and Bourke.

The definitions of terms used in connection with groundwater were reviewed and listed in the Conference Report (ICAW, 1929). The results of various investigations and the usual well data and flow, pressure, temperature, and chemistry data were presented. Rates of diminution of flows and pressures, and information on gases in the water from wells was also tabled. Maps included in the Report show the boundary of the Basin, locations of wells and springs, potentiometric surface contours for 1928 and geological information.

A description of a deep well drilled in New South Wales and information from wells in Queensland revealed the existence of several aquifers with different flows, pressures, and chemical composition. The assumption was made that vertical flow occurred from lower aquifers with higher pressure heads to higher aquifers with lower heads; the separation of the vertically different aquifers was not only proved by difference in flow and pressure, but also by different rates of diminution. Temperature data from wells in New South Wales and Queensland were used to once again contradict and combat the plutonic theories of artesian water by Du Toit (1917) and Gregory (1923). An increase in drilling of shallow (subartesian) wells was reported. Some deep wells had been drilled in search of additional sources of supply of the decreasing flow from the main aquifers; higher pressures were encountered in deeper aquifers, but not always higher flows. Experiments with rotary drilling, and further investigations on corrosion, gas pressures, porosity and texture of aquifers, and correlation of pressures, flow, and temperatures were described. In Queensland subartesian wells were also required to be licensed following a change in legislation in 1926.

Geological mapping was carried out in New South Wales, Queensland, and South Australia, covering almost all marginal areas of the Basin. The mapping provided detailed information on, and minor changes to, the Basin outline and the outcrop of the aquifers. Correlation of deep subsurface aquifers posed many problems, but in the recharge areas redefinition and considerable improvement of the stratigraphy was achieved. In the Northern Territory, drilling confirmed the Basin's western margin, as mapped by Brown (1905) and Jack (1915).

The Report of the Fifth Conference (ICAW, 1929) contains a <u>bibliography related to artesian water in Queensland, New South Wales, and South Australia for the period 1912 to 1928</u>. Appendixes to the Report deal with well data including diminution of flow and pressure, chemical analyses of water and gases, details of water wells of more than 3000 ft (914 m) depth in Queensland, etc. Maps in the report show geological and hydrogeological information, potentials, wells and spring locations, and marginal, high level (perched) basins.

The Fifth Conference recommended that detailed studies be made of the recharge area between Tambo and Springsure and the possible recharge area near Boulia. Other recommendations concerned the systematic storage of information on wells and related data and analyses, on the effects on stock of dissolved solids in the water, and on rock pressure as a cause of the rise of artesian water. It was decided to discontinue the printing of any further graphs of declining flows and pressures of wells and their (constant) temperatures, as the records of sixteen years showed a very consistent pattern; only abnormalities would be considered. A concise review of the state of knowledge regarding the principal artesian basins of Australia was to be prepared for the meeting planned in 1930. The Conference also widened its field to deal with all underground water supplies, investigation and study of which was urgently needed.

The Report of the Fifth Conference shows that progress was still being made in the acquisition and interpretation of data, and that surveys were being continued to define the precise extent of the Basin, both in vertical and lateral sense, during which deeper aquifers were discovered.

The ultimate benefit of the Interstate Conferences was considerable, as they had led to a systematic, common and cooperative approach to many of the problems connected with artesian water such as the diminution of flows and pressures, the origin and movement of the water, the extent of the basin and the corrosion of casing. Many of the investigations had led to adequate explanations, which often had been widely published and had reached the well owners and the general public. This resulted in an organised development of the groundwater resources to the advantage of the well owners and the community. No further meetings were held until 1939, when an Interstate Conference on Water Conservation and Irrigation met in Sydney.

Interstate Conference on Water Conservation and Irrigation, 1939

This conference dealt with almost all aspects of ground and surface water and related matters. The most significant result with regard to groundwater was the resolution by the conference to recommend to the Commonwealth and State governments a combined national investigation of underground water supplies and related matters. Discussions about artesian water dealt almost exclusively with the Great Artesian Basin, and concentrated on the diminution and control of flow, and the improvement in distribution. It was recognised that wastage of water from flowing wells was the main problem; this could be rectified by using pipes instead of earth ditches for reticulation, but this solution would be difficult to introduce because the cost of piping would be about the same as the costs of drilling and maintaining shallow subartesian wells, apart from all the administrative problems.

GEOLOGY AND GROUNDWATER HYDROLOGY INVESTIGATIONS, 1920s TO 1950s

New South Wales

In New South Wales a systematic survey of the geology of the artesian intake beds and the subsurface water resources commenced in 1925, and initially concentrated on the most southeasterly part of the Great Artesian Basin. Results were reported at the Fifth Interstate Conference on Artesian Water (ICAW, 1929) and in Annual Reports of the Department of Mines (Kenny, 1926, 1928a, 1928b, 1929, 1930; Lloyd, 1934) and subsequently by Kenny (1964). A detailed stratigraphic sub-division of the Upper Palaeozoic and the Mesozoic and Cainozoic rocks in the area was established, and an assessment made of the groundwater resources, using well data, details of which are included in Kenny (1964). Different aquifers were identified, the most important waterbearing rocks being in the Pilliga Beds and to a lesser extent in the Garrawilla Lavas.

The geology and subsurface water resources in the western part of the State north and west of Wilcannia are described by Kenny (1931, 1934). He reviewed the earlier work in the area and provided a comprehensive bibliography, and added considerably to the work carried out by Wilkinson (1881), Brown (1881), Pittman (1894, 1895b), and Andrews (1926). Kenny (1934) described the occurrence, lithology, and stratigraphy of the Palaeozoic rocks, the Jurassic sandstones, Cretaceous shales and sandstones, and younger sediments, and provided an assessment of the waterbearing capacity of the aquifers in these rocks. He listed the wells and chemical analyses and discussed the quantity and quality of water obtainable.

The Water Conservation and Irrigation Commission of New South Wales prepared a First Interim Report on an investigation of the supply of artesian water in New South Wales (Tandy, 1939). The study concentrated on hydrodynamics, and attempted to clarify the artesian problem by the theory of the compressibility of aquifers. The Report, accompanied by many geological and potentiometric maps, sections, graphs, and diagrams, continually refers to the results of the Interstate Conferences on Artesian Water, and deals with the historic development of artesian water, diminution of flows and pressure, and surveys of the recharge areas in Queensland and New South Wales, with particular reference to Kenny (1926) and Pittman (1915).

Calculations based on rainfall data, well discharges, and waterlevels led to the conclusion that recharge could easily maintain the waterlevels in the intake beds. Analysis of potentiometric maps showed that the flow of artesian water was concentrated in some areas in New South Wales parallel to present surface streams, and that the potentiometric surface was roughly parallel to the ground surface. The hydraulic gradient pointed to leakage from the Basin by mound springs along the western margin of the Coonamble Embayment and the area of lakes and swamps between Walgett and Bourke. Upward leakage was also suggested, but no evidence for such was available. Pressures and temperatures were found to increase with depth.

The nature of the flow in the artesian aquifers of the Basin was shown to follow Darcy's law, and was confirmed by flow and pressure tests on selected wells. Permeability tests were conducted on samples and the results expressed in darcies, following Muskat (1937). It was concluded that permeability of aquifers around a well decreased with the age of the well, and it was suggested that several causes could account for this, one of these being the increase in radius of action of the well. Permeability values calculated varied from 1 to 10 darcies, and when these figures were applied to the main flowline where a hydraulic gradient existed of 0.38 m per kilometre (2 feet per mile), it resulted in a computed rate of flow of 0.50 m (1.65 feet) per year. Work on a general flow formula resulted in the derivation of an equation which expressed the flowing-life curve of a well, from which it was possible to determine the flow or potential value for the well when the curve tended to become asymptotic; this value was thought to represent the replenishment to the well.

A section in the First Interim Report dealt with earlier theories regarding artesian supplies in the Basin and the theory of compressibility. The plutonic and meteoric theories, which also had been discussed at the Interstate Conference on Artesian Water, were described, as was Russell's (1928) theory that artesian water is connate water, an idea criticised by Piper (1928) and Terzaghi (1929 a, b). Russell's explanation of pressure causing the flow as a result of the weight of overburden through the principle of compressibility had, however, been accepted by his critics. Meinzer (1928) had previously described the theory of the compressibility and elasticity of artesian aquifers. Application of data from the Great Artesian Basin to equations developed by Terzaghi (1929 a, b) describing compressibility and elasticity showed that water in excess of the steady state flow originated from the compression of aquifers. This meant that water hitherto withdrawn from the Great Artesian Basin had come from local storage and was irreplaceable, and that the ultimate steady state supply, which should correspond to the replenishment, would be much less than the supply obtained at the time of the investigation. So an adequate supply and pressure could be maintained for a longer period if wells were closed down periodically or partly closed permanently. This, however, could only be achieved if a less wasteful method of distribution could be adopted to replace the open earth channels, from which, according to estimates, only 10% of the continuous water flow was consumed by stock. Several proposals for the control of seepage and evaporation losses were made, including baking of the soil by applying heat to the channel surface causing soil stabilisation using cement, rubber, and asphalt, and the use of sodium carbonate to make the channel surface impermeable. Consideration was also given to the water losses from wells by corroded and leaking casing.

A Second Interim Report was prepared in 1940 by the Water Conservation and Irrigation Commission of New South Wales following the First Interim Report in 1939 and the Interstate Conference in 1939. The Second Interim Report (Tandy, 1940) emphasised that action should be taken to conserve the artesian water supplies. It discussed the intake areas, and considered the artesian groundwater flow from Queensland more important than any supply from the southeastern margin in New South Wales. Potentiometric maps were attached and hydraulic gradients determined. Cross-sections demonstrated a related between potentials and temperatures, an increase of temperature, and a decrease of mineral content with deeper aquifers. Mound springs were shown to coincide with linear features. Further work on the theory of compressibility was reported on, and it was stated that the ultimate steady state flow should be equal to recharge. Tests on the interaction of closely adjacent wells were carried out to determine permeability, and casings were tested to calculate friction factors.

It was estimated that the accumulated ultimate steady state flow of wells in the eastern part of the Great Artesian Basin in New South Wales would approximate $72.7 \times 10^3 m^3$/day (16×10^6 gallons per day). This artesian supply was said to be sufficient for stock water supply, considering the carrying capacity of the land for stock and the average water consumption, if a distribution system of Fibrolite pipes were used. These pipes should be economical, and should also eliminate seepage and evaporation losses.

Dulhunty (1939 a, b, 1940) reported results of geological investigations in the southeastern marginal area of the Basin, and described the boundary and hydraulic relation between the Great Artesian Basin and the Oxley Basin in the Gunnedah-Mudgee area.

Mulholland (1944) described the geology and the water-bearing properties of the stratigraphic units in the southern part of the Coonamble Embayment, south of a line from Narrabri to Coonamble. He demonstrated that the rate of withdrawal for the area was greater than the available recharge and as no fall seemed to have occurred in the heads of the intake beds, the source of excess water and the cause of fall in potential was explained by the compressibility or artesian aquifers, in which he followed the theories of Meinzer (1928) and Terzaghi (1925). He made some observations on the amount of water removed by compaction, and the subsidence due to the release of this water.

Rade (1954a) investigated the northern part of the Coonamble Embayment from Narrabri to the Queensland border, dealt with the stratigraphy, and presented structure contour maps of the main aquifer (Pilliga Sandstone) and the basement rocks in the area. Separate aquifers were shown to be distinguished by different rates of flows and different chemical characteristics of the water. The direction of movement and the chemical composition of groundwater and the geological structure of the basement rocks were compared and it was shown that a relation existed between them.

Rade (1954c) described the geology of the recharge area from Warialda to the Queensland border, and the water-bearing properties of the stratigraphic units. The significance of the Pilliga Sandstone as an aquifer was confirmed, and the direction of groundwater movement in the area shown to be northwesterly.

Rade (1955) reported on the geology and groundwater of the southwestern part of the Coonamble Embayment. In this area he found that salinity increased from east to west, corresponding with the flow direction, and attributed this to lithological changes due to a westward increase in the ratio of shale and disseminated pyrite within Mesozoic rocks. He also described mound springs in the western margin of this part of the Basin between Coonamble and Bourke.

The geology and groundwater of the area north of the Darling River between longitudes 145° and 149° was dealt with by Rade (1954b). He suggested that the movement of artesian water is closely controlled by the configuration of the Palaeozoic basement, and that all mound springs north of Bourke are located on faults and intersections of faults.

South Australia

Jack (1925) investigated Cretaceous and Cainozoic aquifers in South Australia, in an area which was west and northwest of that later described by Kenny (1934), and recognised the importance of these shallow aquifers for the northeastern part of South Australia and the area around Lake Frome. These aquifers, which occur above the main (Jurassic) artesian beds of the Basin, had been reported at the 4th and 5th ICAW (1925, 1929). Jack (1925) suggested that the chemical characteristics of the water from different aquifers varied significantly and could be used for correlation. He noted that the Cretaceous aquifers produced less water, and that the water was inferior in quality to water from the main Jurassic aquifers; this fact was noticed by Kenny (1934), who also recorded the phenomena of high salinity water from Cretaceous aquifers in New South Wales.

Jack (1930) published a paper on groundwater in portions of South Australia which includes a review of the South Australian part of the Great Artesian Basin. He described the geology and occurrence of aquifers in the Basin and depicts aquifers on geological cross-sections which also show the waterlevels and water quality. Groundwater movement was explained using potentials and chemical composition of the water. Chemical analyses were also used to show that leakage of water from Jurassic to Cretaceous and Cainozoic aquifers occurs in areas east and north of Lake Frome (see also Fifth ICAW, 1929).

Ward (1946) dealt with the occurrence, composition, testing, and utilisation of groundwater in South Australia. His review paper contains a section on the Great Artesian Basin which is accompanied by tables concerning well data, aquifers, waterlevels, and results of chemical analyses. Much of this information was earlier published in reports of ICAW and by Jack (1923, 1925, 1930). Ward's paper reviews the geology of the Basin, the direction of the movement of the groundwater as deduced from potential maps, the diminution of flow and pressure, recharge and discharge areas, mound springs, chemical characteristics, and the utilisation of the water. It also reviews earlier literature on the source of the artesian water and the cause of its rise, referring to the literature from the 1920s and 1930s about the influence of rock pressure in confined aquifers or the compression of the aquifer by the overlying rocks according to the elastic storage principle of Russell (1928), Meinzer (1928), Tolman (1937), and others. The paper was later published in a slightly altered form (Ward, 1950, 1951). Chebotarev (1955) reported on some hydrochemical data from the Basin.

Queensland

Following the Interstate Conference in Sydney in 1939 a committee was set up in Queensland in the same year to investigate the incidence of artesian water supplies. Geologists and engineers, assisted by Dr. F.W. Whitehouse (geologist, University of Queensland) and C. Ogilvie (engineer, Department of Irrigation and Water Supply), formed the Committee of Investigation to ascertain the nature and structure of the Great Artesian Basin, especially from the point of view of its water content and sources of supply, and to study the geological, physical, and chemical aspects of the problem of diminishing water supply.

The objective was to produce statistical and graphical presentations of the phenomena of declining yield and the general controls of the Basin, which together could be used for the formulation of a State policy on the use and conservation of water. A First Interim Report was presented by the committee in 1945 (Queensland Government, 1945); the committee had decided to make a scientific inquiry into the geology and hydrology of the Great Artesian Basin and review the economic and legislative factors related to the use and conservation of water. The report mainly dealt with geology, hydrology, the use of water, and diminution of flows and pressures. In its conclusion it emphasised the principles of recharge, elastic storage, the resulting diminution of flows and pressures and the gradual decrease in diminution, and the importance of water conservation by the control of wells.

The report includes a review of the different artesian theories, a description of the use and the extent of areas of artesian supplies, and of the quantity and quality of the artesian water. The principle of elasticity of the aquifers, as developed by Meinzer and Theis in the USA, was dealth with, and the diminution of flows and pressures explained, as well as the expanding radius effect of wells, which previously had been thought to be constant. The total discharge was estimated at 1.2×10^6 l/sec or $1.04 \times 10^6 m^3$/day (229×10^6 gallons per day) in 1943, or less than two-thirds of the maximum flowing supply of 1.8×10^6 l/sec or $1.61 \times 10^6 m^3$/day (355×10^6 gallons per day) in 1914. The total accumulated discharge of flowing wells in the Queensland part of the Basin to the end of 1943 was estimated at $23.6 \times 10^9 m^3$ (5 197 358×10^6 gallons), or the equivalent of 0.02362 m (0.93 inch) over the Queensland part of the Basin. These calculations assume that the intake areas amounted to 77699 km^2 (30 000 square miles) and that the porosity of that area was 20 percent. If no recharge had occurred since the drilling of the first well, the water levels in the intake area would have been lowered by 1.524 m (5 feet). The annual flow from all wells at that time (1945) was equivalent to about 0.005 m (one-fifth of an inch) over the area of the intake beds. The average annual rainfall over that area is about 635 mm (25 inches) and as a result there had been no appreciable reduction of water level in the intake beds. It was stated that the diminution of flow was caused by the elastic effect of the aquifers, and not by lowered intake water levels. Flow from wells would proceed, after complete release of the elastic pressure, as a steady flow which would depend on the amount of recharge, hydrostatic pressure, and altitude. Comments were included on the purpose and performance of pressure tests on wells, together with some flow and pressure data, and on temperature, gas content, and chemical analyses. It was proposed to use the chemical data for investigation of the direction of flows in combination with pressure test results.

Appendices to the First Interim Report contained details by Whitehouse and Ogilvie about the geological and hydrological investigations. The geological work concerned the stratigraphy of the Basin in the eastern outcrop areas and in the subsurface, and the hydrological investigations dealt with flow and pressure tests on wells, the diminution of flows and pressures, and predictions on future flows.

The Artesian Water Investigation Committee produced in 1954 a 'Report on the Artesian Water Supplies in Queensland, following First Interim Report (1945) of Committee appointed by the Queensland Government to investigate certain aspects relating to the Great Artesian Basin (Queensland portion) with particular reference to the problem of diminishing supply' (Queensland Government, 1954).

This 1954 report is the most comprehensive description of detailed investigations on the hydrogeology of the Queensland part of the Basin. Appendices to the report, which were published separately, provide detailed descriptions of the geology (Whitehouse, 1954) and hydrology (Ogilvie, 1954). The report describes the nature and structure of the Queensland portion of the Great Artesian Basin, with emphasis on the quantity of water and its aquifer system, and the study of geological, physical, and chemical aspects of the problem of diminishing supply. It is accompanied by statistical and graphical data of the phenomena of declining yield. The report contents formed a basis upon which a State policy for the use and conservation of water was defined, and led to recommendations stating the principles and methods by which the maximum benefits could be obtained from artesian supplies.

Recommendations in the report concerned the proper use, regulation, and control of water from wells and the recommendation not to begin strict conservation of flows from existing artesian wells.

The Committee's Report concluded that the Great Artesian Basin exhibited all the characteristics of a typical artesian system in spite of its vast size and complexity. During initial development, water was derived from elastic storage and perennial recharge from the intake areas. A steady state would be reached when no more water could be drawn from elastic storage in the aquifers or in the saturated less permeable confining beds and discharge from the Basin became equal to recharge. The recharge was calculated and a comparison made of the costs of alternative facilities that could replace wells which ceased flowing, and the costs of a conservation program to minimise further diminution of flow.

The result of the assessment was that artesian diminution was not considered to be a threat, only a disability, that recharge to the Basin was shown to occur, and that water would always be available at pumping depths in areas where wells ceased flowing. In view of the fact that pumping supplies and surface water resources would always be available it was decided that a stringent conservation programme was not economically justifiable. It was considered preferable to allow the 4.7×10^9 m^3 (3.8×10^6 acre-feet), which would be withdrawn from elastic storage in the 60 years following 1950 if no conservation program was implemented, to be used rather than to conserve it, as the approximate costs to conserve artesian water supplies by restricting well flows and improving drain distribution systems would only be slightly less than the costs of replacement facilities and wells to provide alternative water supplies (1950 conditions).

Approximately 31.8×10^9 m^3 (25.8×10^6 acre-feet) water had been withdrawn from the aquifers in Queensland during the period 1890 to 1950 by flowing and pumped wells and springs and by leakages into other States; 22.5×10^9 m^3 (18.3×10^6 acre-feet) came from elastic storage and 9.3×10^9 m^3 (7.5×10^6 acre-feet) from recharge during that period. Decreases in regional heads amounted to approximately 120 m (400 feet) in some areas.

If no further action were to be taken, 660 wells would cease flowing during the 50 to 60 years following the report date in addition to the wells which already had stopped flowing, and about 500 wells would continue to flow forever with a reduced yield averaging more than 910 m^3/day (200 000 gallons per day).

If a conservation program restricted discharge from flowing wells to 50 percent, and distribution was such that discharge equalled recharge in all regions (with a total recharge of 0.568×10^6 m^3/day (125×10^6 gallons per day)), it would be possible to maintain regional pressures and prevent further diminution of flow, and nearly 1200 wells would flow forever at an average of about 409 m^3/day (90 000 gallons per day) and 45.5×10^3 m^3/day (10×10^6 gallons per day) would discharge from springs and pumped wells and a similar amount move as underflow across the State borders.

With no strict control and no appreciable expansion of the existing system, the steady-state flow from 500 permanent flowing wells would be reached in about 60 years (in the year 2010), and amount to 500×10^3 m^3/day (110×10^6 gallons per day). At that stage the discharge from wells pumped with windmills, from springs and other leakages and from underflow across the Queensland State borders would be about 90×10^3 m^3/day (20×10^6 gallons per day), making a total discharge from the Queensland portion of the Basin of about 590×10^3 m^3/day (130×10^6 gallons per day). The recharge would also be about 590×10^3 m^3/day (130×10^6 gallons per day) - (these figures have since been revised - see later).

The right order of magnitude for these statistical estimates of the recharge were confirmed by using data on transmissivity and hydraulic gradient values. Transmissivities averaged 400 m^2/day (27000 gpd/ft), within a range from about 100 to 1000 m^2/day (6590 to 64000 gpd/ft), the average hydraulic gradient was about 1:754 (7 feet per mile), and the length of effective intake area was 960 km (600 miles). An underflow of 590×10^3 m^3/day (130×10^6 gallons per day) required a transmissivity of 460 m^2/day (31000 gpd/ft) in the intake areas.

The original recharge to the Basin was estimated at 295×10^3 m^3/day (65×10^6 gallons per day), and this had increased to 568×10^3 m^3/day (125×10^6 gallons per day) at the report date, as a result of the increasing number of wells and the falling pressures and steepening of the hydraulic gradient.

If the existing flows were restricted to 50 percent, with recharge being equal to discharge in all regions, the final steady state discharge from about 1200 flowing wells in Queensland would be about 477×10^3 m^3/day (105×10^6 gallons per day). This final steady state flow would be about 23×10^3 m^3/day (5×10^6 gallons per day) less than the flow if such restrictions were not imposed, but it would be spread over a larger flowing area because wells at higher levels would continue to flow.

With maximum efficiency of well drains, an ultimate discharge of 455×10^3 m^3/day (100×10^6 gallons per day) from flowing wells would provide sufficient water for the distribution system in existence at the report date: about 27 400 km (17 000 miles) of open earth drains, averaging 16 m^3/km/day (6000 gallons per mile per day). Restrictions on well discharge, and the use of efficient distribution systems had already led to conservation of water, which would be improved even further by flow restrictions and well reconditioning. However, as mentioned already, implementation of a conservation program was not considered to bring sufficient benefits, and, further, though flowing artesian water is the most convenient and economical method for stock watering, it is not essential, especially not if pumped supplies are always available when wells cease to flow. Stock use less than ten percent of the flowing water distributed by open well drains, a system which could be greatly improved by the use of piping.

The report states that the quality of artesian water from the greater part of the Basin is unsuitable for prolonged use for irrigation on most soils. It was considered that domestic and stock requirements should have priority, and that no artesian water should be used for irrigation unless surplus water was available. Almost the whole of the final steady-state discharge from flowing wells, 500×10^3 m^3/day (110×10^6 gallons per day) would be needed to serve well drains in the flowing area. The estimate was that, 4.7×10^9 m^3. (3.8×10^6 acre-feet) would be withdrawn from the elastic storage in the 60-year period following 1950 if no conservation program was implemented, and that the total withdrawal from aquifers in Queensland during this period would be 17×10^9 m^3 (13.9×10^6 acre-feet) of which 12×10^9 m^3 (10.1×10^6 acre-feet) would be provided by recharge to the Basin.

Other items in the 1954 report deal with descriptions of the artesian principle and the geology and hydrogeology of the Great Artesian Basin, the history of artesian well drilling in Queensland since 1885, the use and distribution of artesian water, and detailed data about wells, discharges, pressures, and tests on wells. Descriptions included the general characteristics of well completion and headworks, and the practice of pressure cementing since about 1940; most wells contained several strings of casing, usually an outer casing of 203x7 mm (8x9/32 inches), and an inner casing of 152x4.7 mm (6x3/16 inches), and, for wells over about 900 m (3000 ft), an additional 254 mm (10 inch) diameter casing.

The report contained a summary of the legislative history relating to artesian water in Queensland. A minority report criticised some aspects of the main, majority report, and expressed doubt about the inadequate premises and conclusions reached. It also recommended studying the Great Artesian Basin as an entity, in combination with the other States involved.

The report appendices by Whitehouse and Ogilvie describe in detail the geology and hydrology of the Queensland part of the Great Artesian Basin, and represent the result of extensive field and laboratory studies. Whitehouse (1954) gives a comprehensive outline of the stratigraphy of the Basin, with emphasis on the Mesozoic sequence, and its correlations and distribution; he also deals with the aquifer systems, leakages (springs), and intake areas. The origin of the Basin, the pre-Mesozoic basement, its structure, and the Cainozoic sediments and surface features (soils and geomorphology) are also described.

Ogilvie (1954) reports on the tests carried out on wells, and the hydrodynamics, transmissivity determination, and interference effects, on pressure and flow distribution, the volumetric history of flows, the diminution of flow and its various causes, the distribution system, chemistry, and temperatures of the artesian water, and a chapter on remedial measures which contains items ranging from artificial recharge, piping, water rights, and replacement facilities to economic considerations and recommendations. Many graphs, maps, and photographs, the photographs showing mainly wells, springs, well drains and geological features, illustrate the report. Ogilvie recommended the partial restriction of flows in order to preserve flows and pressures; this restriction would have to be controlled by annual determination of the diminution of selected wells and by the testing of wells to determine the transmissivity and storage coefficient values - reconditioning of some wells would have to follow.

Implementation of a conservation program would reduce the flow from 1.03×10^6 m^3/day to 0.7×10^6 m^3/day (226×10^6 to 160×10^6 gallons per day) for Queensland, and would reduce the excess demand on recharge by half. It was shown that about half of the free flow of wells in Queensland would, at optimum efficiency, be sufficient to serve the existing open earth drain system, with drains served by individual wells having lengths of almost 200 km (up to 120 miles). With permanent restriction to half of the 1950 flows, the rate of diminution would disappear in some regions and become nominal in all except those in a small area in southern central Queensland.

General review

A general description of the Great Artesian Basin is given in David (1950), which briefly deals with most aspects of geology, hydrology, salinity, temperature, diminution of flow, and exploitation. Some detailed data are included in that report.

GEOLOGICAL INVESTIGATIONS, 1960s AND 1970s

Geological surface mapping by BMR and State Geological Surveys during the 1950s, 1960s, and early 1970s produced geological maps at a scale 1:250 000 with accompanying notes covering most of the Great Artesian Basin area, and maps at a scale of 1:1 000 000 covering the Basin in Queensland, New South Wales, South Australia, and Northern Territory. Synthesis of the regional geology of parts of the Basin covered by maps at scales 1:250 000 and 1:1 000 000 were in preparation during the study.

The Great Artesian Basin is now said to comprise the sedimentary Eromanga, Surat, and Carpentaria Basins and small upper parts of the Bowen and Galilee Basins (Fig. 2; Habermehl, 1980a). Confined aquifers within the Basin consist mainly of Triassic, Jurassic, and Cretaceous continental sandstones. The aquifers alternate with low to very low permeability confining beds consisting of siltstone and mudstone of continental or shallow marine origin. The constituent basins are mainly very broad synclinal structures trending northeast (Eromanga) or north (Surat and Carpentaria). They are contiguous across shallow ridges and platforms of older sedimentary, metamorphic, or igneous rocks (Fig. 2). Similar rocks of pre-Jurassic age underlie the constituent sedimentary basins, and represent the impervious hydrogeological basement.

The Mesozoic sedimentary sequence present in the Great Artesian Basin reaches a maximum total thickness of about 3000 m in the central part of the Eromanga Basin. Marginal parts of the constituent geological basins have been partly eroded, particularly along the eastern rim which was uplifted during Cainozoic times. Sheet-like rock bodies are characteristic of the sedimentary basins, and persist relatively unchanged for hundreds of kilometres.

Several hundred petroleum exploration wells were drilled in the area during the 1960s and 1970s, particularly in parts of the Surat, Cooper, and Adavale Basins. Lithological and wire-line logs provided subsurface data and facilitated correlation between lithostratigraphic and hydrogeological units.

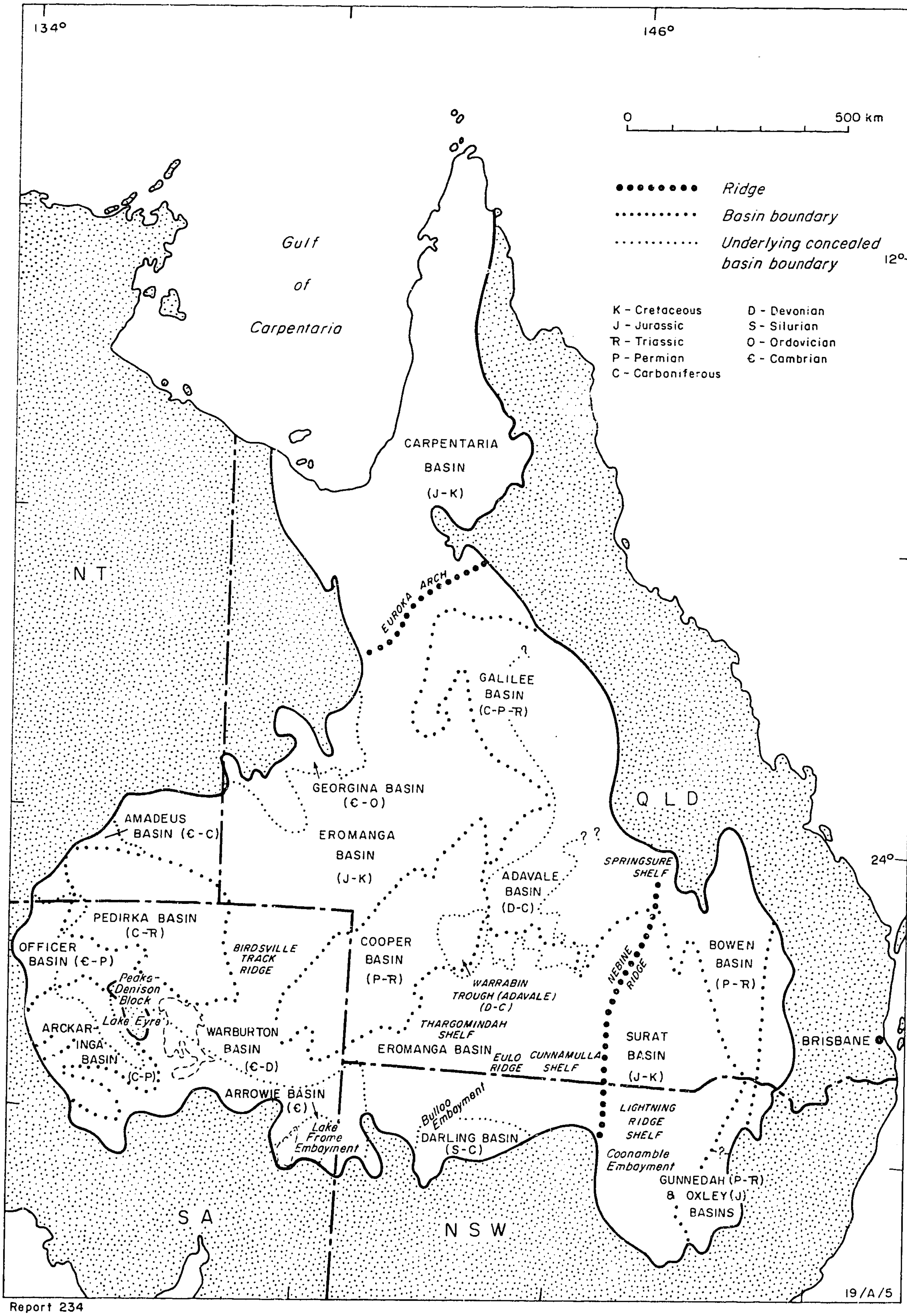

Fig. 2 Constituent sedimentary basins and intervening intermediate ridges and outlines of pre-Jurassic basins and their ages

Pressure measurements and fluid recovery from aquifers during formation tests in these petroleum exploration wells provided some information though most of these drill stem tests have been carried out in the pre-Jurassic sequence. Well completion reports are available in the Petroleum Search Subsidy Acts publication series of BMR or in unpublished form; other well completion reports are held by the relevant State Mines Departments.

Stratigraphic drill-holes, both shallow and deep, have been drilled and described by BMR and the State Geological Surveys. These holes penetrated the whole or parts of the Mesozoic sedimentary sequence in areas of New South Wales, South Australia and eastern Queensland.

Water-well drillers' logs of variable quality are available for most flowing artesian wells, fewer for non-flowing artesian wells. These records, which are held by the State Water Authorities or Departments of Mines, contain a large amount of technical, lithological, and hydrological data.

Wire-line logs of water wells in the Great Artesian Basin were obtained by BMR and contractors to BMR for about 1250 water wells during the period 1960 to 1975 (Habermehl & Morrissey, 1980, in prep). These logs enabled identification and correlation of formations and hydrogeologic units during the present study and provided many other data. Almost all existing water wells are lined with metal (steel) casing in the form of a single string or several strings of different diameter (usually about 300, 250, 200, or 150 mm), and this restricts the type of wire-line logs which can be run in the wells. Natural gamma-ray logs are available for all water wells logged; in addition, for most wells, casing collar locator, temperature, and differential temperature logs were run. In some wells flowmeter, neutron-gamma, spontaneous-potential, resistivity, and caliper logs (Habermehl, 1980b; Habermehl & Morrissey, 1980, in prep) were also run (the electric logs were obtained from newly drilled wells or wells with a large interval of open hole at the bottom). In the New South Wales part of the Great Artesian Basin about 235 water wells were logged by the Geological Survey of NSW during 1965 to 1975, and in South Australia 17 wells were logged by the Geological Survey of SA during 1966 and 1967. No logging was carried out in Qld or NT by the relevant Geological Surveys.

Descriptions of the regional geology of parts of the Great Artesian Basin (Habermehl, 1980a), or of the constituent sedimentary basins, contain most of the recent references to geological investigations (Exon, 1976; Senior & others, 1978; Hawke & others, 1975; Parkin, 1965). Many references are also included in the Explanatory Notes of the 1:250 000 geological map sheet series which cover most of the Great Artesian Basin (Fig. 3), and in published and unpublished reports of geological activities by BMR and State Geological Surveys (Casey, 1968; Cramsie, 1973, 1974, 1975).

The Eromanga Basin (Fig. 2), contains a conformable, almost horizontal sequence of Lower Jurassic to Upper Cretaceous sedimentary rocks (Parkin, 1965; Wopfner & others, 1970; Exon & Senior, 1976; Vine, 1976a; Senior & others, 1978).

The southeastern part of the Great Artesian Basin is the sedimentary Surat Basin (Power & Devine, 1970; Exon, 1974, 1976; Allen, 1976; Exon & Senior, 1976). It contains 2500 m of nearly horizontal sedimentary rocks of Jurassic and Cretaceous age.

The Coonamble Embayment (Hind & Helby, 1969; Bourke & others, 1974; Hawke & others, 1975; Bembrick, 1976b) forms the southern part of the Surat Basin, and is separated from the main part of the basin by the Lightning Ridge Shelf.

The Jurassic rocks overlying the Gunnedah Basin in the most southeastern part of the Great Artesian Basin are referred to as the Oxley Basin (Bembrick & others, 1973; Bourke & others, 1974; Bourke & Hawke, 1977).

The northern extension of the Great Artesian Basin is the Carpentaria Basin (Doutch, 1976; Smart & others, 1980). It contains continental rocks of Jurassic age, and mainly marine sedimentary rocks of Cretaceous age.

The uppermost sandstones in the Triassic sedimentary sequences of the Bowen and Galilee Basins contain aquifers which form part of the Great Artesian Basin; they are partly overlain by the Eromanga and Surat Basins. The Bowen Basin (Exon, 1974; Jensen, 1975; Paten & McDonagh, 1976) contains Permian and Triassic sedimentary rocks and forms an elongate, northerly trending basin.

The Galilee Basin (Vine, 1976b) contains up to 3000 m of mostly continental sediments of Late Carboniferous to Triassic age.

Cainozoic rocks

The Great Artesian Basin is partly concealed by mostly unconsolidated Cainozoic continental sediments as much as 150 m thick. These deposits mainly occur over the northeastern and southwestern parts of the Eromanga Basin, and cover almost the whole of the Surat and Carpentaria Basins (Wopfner & Twidale, 1967; Wopfner & others, 1974; Wopfner, 1974; Smart & others, 1980).

They rest on the deeply weathered erosional surface of the Cretaceous sediments; the older, Tertiary, sediments are also partly weathered and silicified.

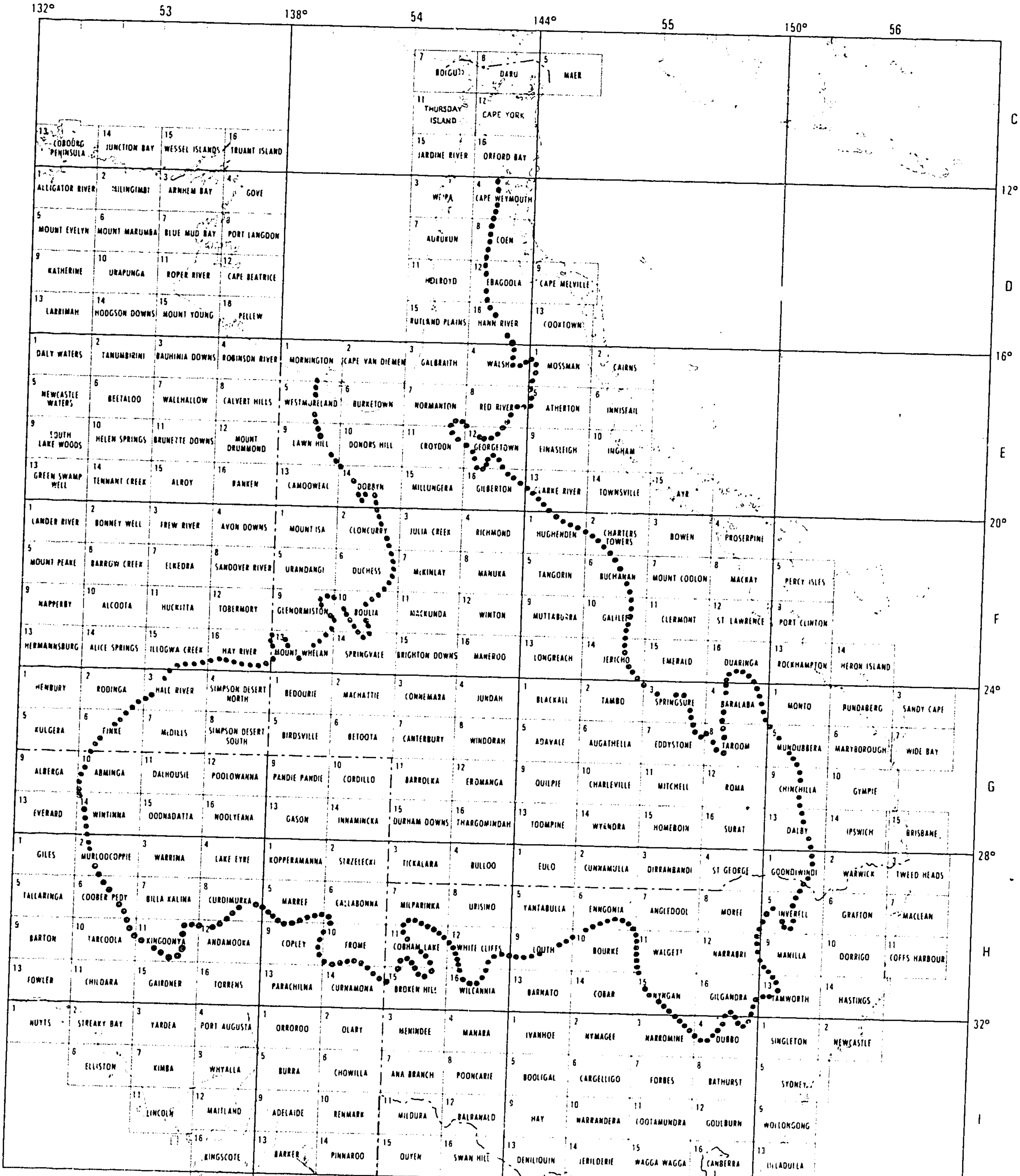

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Fig.3 Great Artesian Basin 1:250 000 map sheet index

In the northeastern part of the Eromanga Basin, the northern part of the Surat Basin and the eastern part of the Coonamble Embayment Tertiary basalts cover some areas of Mesozoic rocks.

Stratigraphy

The stratigraphic succession present in the hydrogeologic Great Artesian Basin is given in summary form, excluding local marginal facies equivalents and minor units, in Habermehl (1980a). The distribution and correlation of these rock units of Middle or Early Triassic to Late Cretaceous ages in the sedimentary Bowen, Galilee, Eromanga, Surat and Carpentaria Basins, which constitute the hydrogeologic Great Artesian Basin are given in Figure 4.

Detailed descriptions of the lithostratigraphic units, their nomenclature and associated information is given in Hind & Helby (1969), Wopfner (1969), Wopfner & others (1970), Hawke & others (1975), Senior & others (1975), Exon (1976), Exon & Senior (1976), Smart (1976), Senior & others (1978) and Smart & others (1980).

Structure

The Great Artesian Basin is an asymmetrical basin, elongated northeast-southwest, and tilted towards the southwest. The southern and northeast margins have slopes of about 2°, but in the west and southwest the regional dip increases to about 5°.

Tertiary uplift along the eastern margin, and subsidence in the central and southwestern parts, led to the basin's asymmetry and the present dominant southwesterly groundwater flow.

GROUNDWATER HYDROLOGY STUDIES, 1960s AND 1970s

Following the major studies in Queensland and New South Wales during the 1940s and 1950s, the emphasis during the 1960s and 1970s was on detailed geological work in the Great Artesian Basin. Though hydrological studies formed part of this, few specific hydrological studies were carried out by the States.

In New South Wales Williamson (1966) reviewed the early development of the Great Artesian Basin, in particular the construction of the first flowing artesian well in the Basin (Kallara No. 1 or Wee Wattah, in the New South Wales

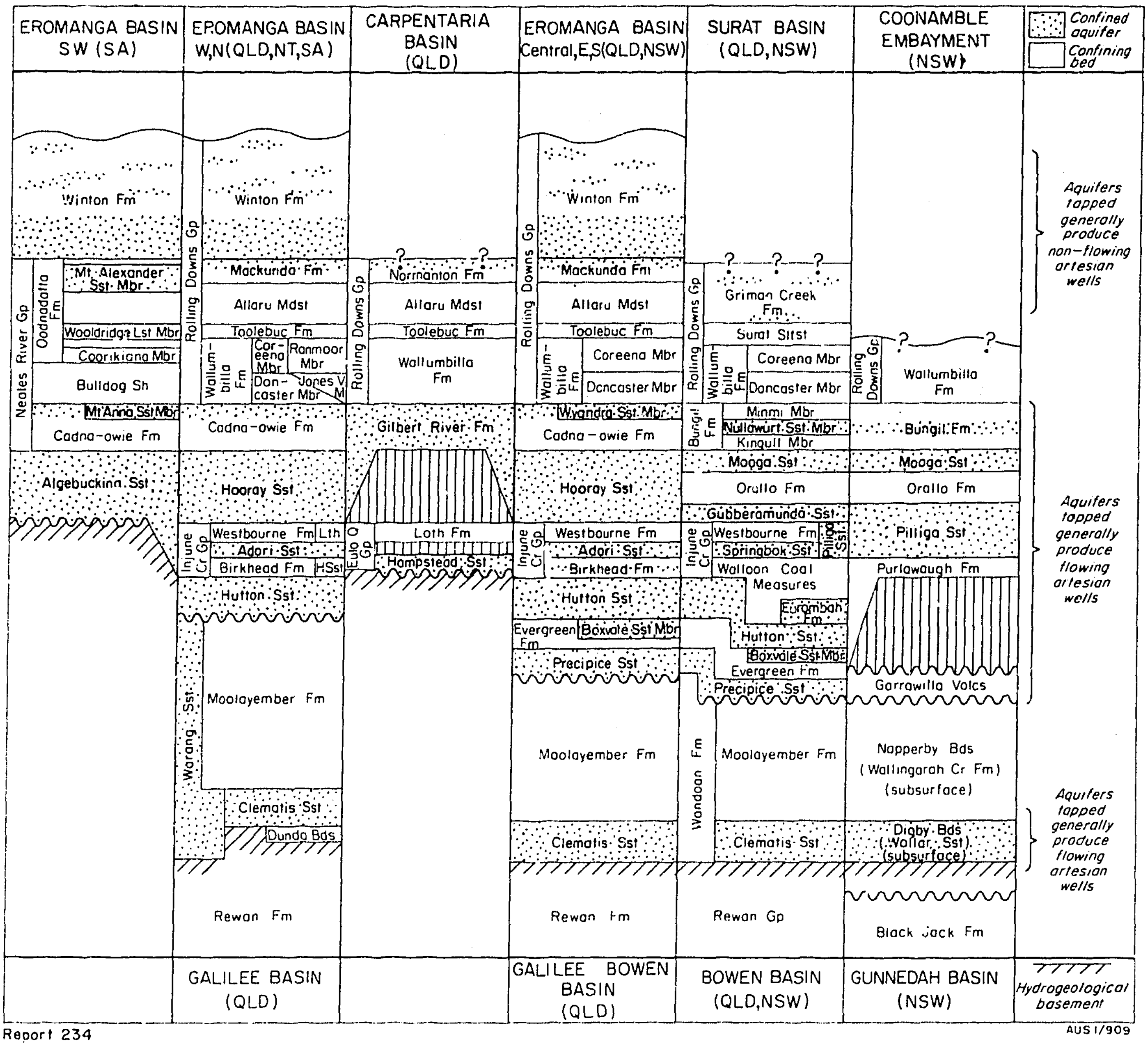

Fig. 4 Correlation of lithostratigraphic and hydrogeological units in the Great Artesian Basin (after Habermehl, 1980a, fig. 10)

part) during 1878. He further summarised most of the early problems, the Interstate Conferences, and the role of the Water Conservation and Irrigation Commission (now the Water Resources Commission) of New South Wales.

Hind & Helby (1969) described the geology and hydrology of the New South Wales part of the Basin. Details of the Basin structure, basement, and geothermal gradients are given, as well as a detailed description and correlation of the stratigraphy. The section on hydrology shows a map with the general directions of water movement, areas of flowing artesian conditions, and locations of mound springs. Water movement is said to vary between 1.6 km in about 150 years and 1.6 km in over 1000 years in the Coonamble Embayment. The report stated that some 3000 wells obtain water from the Basin in New South Wales, and that, in 1968, 682 were flowing artesian wells with a combined (unrestricted) flow rate of 289 x 10^3 m^3/day (63.69 x 10^6 gallons per day). The remainder yielded pumping supplies ranging from several tens of m^3/day (several hundred gallons per hour) to 3.8 x 10^3 m^3/day (35 000 gallons per hour).

Information on exploration, development, and administration of the Great Artesian Basin in New South Wales is presented in Water resources of New South Wales by the Water Conservation and Irrigation Commission (1971). Detailed work on the geology and hydrogeology of the Great Artesian Basin in New South Wales was also carried out by Dulhunty (1973) and the Geological Survey of New South Wales during the late 1960s and 1970s. Results of mapping, drilling, and hydrogeological studies are described in many unpublished and published Reports (Cramsie, 1973, 1974, 1975; Hawke & others, 1975; Bourke & Hawke, 1977). Andrews (1975, 1976) considered specific hydrologic aspects.

In <u>Queensland</u>, geological and hydrogeological work continued, and produced new or revised information on the Basin.

In the Explanatory Notes with the 1:2 500 000 map of the Groundwater Resources of Queensland (Geological Survey of Queensland and Irrigation and Water Supply Commission, 1973) some new figures were published relating to the 1954 report (Queensland Government 1954). In 1954 it was estimated that the increase in recharge which tended to offset the pressure losses, would reach a steady state in the year 2010, when the total discharge would equal the recharge. As previously stated, the recharge would have risen to 590 x 10^3. m^3/day (130 x 10^6 gallons per day); the discharge would consist of 500 x 10^3 m^3/day (110 x 10^6 gallons per day) from flowing wells, 45 x 10^3. m^3/day (10 x 10^6 gallons per day) from pumped wells and springs and 45 x 10^3 m^3/day (10 x 10^6 gallons per day) for aquifer flow into other States.

Studies between 1954 and 1973 confirmed the general trends of the earlier (1954) work, but the 1973 publication estimated the ultimate steady output of the wells at 590 x 10^3 m^3/day (130 x 10^6 gallons per day), underflow to other States at 90 x 10^3 m^3/day (20 x 10^6 gallons per day), and recharge at 680 x 10^3 m^3/day (150 x 10^6 gallons per day). The report states that pressure gradients steepened from an initial 1:2933 (1.8 feet per mile) to about 1:1760 (3 feet per mile) at the time of the report, and, as the front of reduced pressure reached the recharge zones, more recharge water was permitted to enter the aquifer and was transmitted through it.

Further estimates in the report assume that 22.2 x 10^9 m^3 (18 x 10^6 acre feet) of water is stored within economic pumping depths, and 166.5 x 10^9 m^3 (135 x 10^6 acre feet) below such depths. These volumes occur in elastic storage; 20.969 x 10^{12} m^3 (17 x 10^9 acre feet) of unavailable water is retained in aquifer pore spaces. The report lists the computed total withdrawal from the Basin up to 1973 as 35.1 x 10^9 m^3 (28.5 x 10^6 acre feet), 70 percent of which has come from elastic storage.

The report reiterated that the most economical long term policy to conserve the water resource was not to undertake expensive reconditioning of old flowing wells nor maintain the existing area of flowing wells, but rather to aim at an ultimate total withdrawal rate for flowing and pumped wells commensurate with natural recharge rates under equilibrium.

Randal (1978) described the hydrogeology of a small area near the northwestern margin of the Basin.

Conybeare (1970), Hitchon & Hays (1971) and Scorer (1966) worked on the relationship of hydrodynamics and hydrocarbon occurrences.

In South Australia, geological and hydrogeological studies were carried out and reported by Chugg (1957), Forbes (1961), Ludbrook (1961), Ker (1963, 1966), Stanley (1971) and Sheperd (1978). At the request of BMR during its Hydrogeological Study of the Great Artesian Basin, measurements were made by geologists of the Geological Survey of South Australia on the mound springs in the southwestern margin of the Basin. Results were reported by Cobb (1975), Williams (1974, 1979), Williams & Holmes (1976, 1978), and Holmes & others (1981). Armstrong (1981) described the predicted effects of a proposed well field development.

The publication 'Groundwater Resources of Australia' (Australian Water Resources Council (AWRC), 1975) contains a section on the Great Artesian Basin. The geology and hydrogeology of the Basin is described on a State basis. The discharge from the Basin is reported to be about 540 x 10^6 m^3/year (1.48 x 10^6 m^3/day), subdivided over: Queensland 330 x 10^6 m^3/year, New South Wales 130 x 10^6 m^3/year, South Australia 75 x 10^6 m^3/year, and the Northern Territory 1 x 10^6 m^3/year (a total of 536 x 10^6 m^3/year).

Plate 5 in that publication shows a photograph of the Bedourie Town well at Bedourie in Queensland, which the text alleged has a flow of 70 x 10^3 m^3/day (810 l/sec). However, Bedourie Town (WRC-Qld RN316) had a weir measured maximum flow rate of 12 x 10^3 m^3/day or 139 l/sec (2649 x 10^3 gallons per day) in 1905, and 3.8 x 10^3 m^3/day or 44 l/sec (842 x 10^3 gallons per day) in 1970. Other flowing artesian wells in this area had maximum flows of 70 to 85 l/sec during the early decades of this century. Maximum flow rates of individual wells in the area during 1970 were about 3.5 x 10^3 m^3/day or about 40 l/sec.

Figures listed for the Great Artesian Basin in the Review of Australia's Water Resources 1975 (AWRC, 1976b) include a range of common well yields from 0.4 to 5.2 x 10^3 m^3/day. The abstraction during 1974 is listed as 526 x 10^6 m^3, the estimated annual recharge as 410 x 10^6 m^3, and the estimated number of wells as 22770.

THE BMR HYDROGEOLOGICAL STUDY OF THE GREAT ARTESIAN BASIN, 1971 TO 1980

A preliminary meeting of Federal and State representatives with groundwater interests was held in Sydney in 1959, following action by the Commonwealth of Australia, after considering a (1955) report by the Australian Academy of Science, to revive the ICAW (1928) with its terms of reference widened so as to include the consideration of all underground water. An Underground Water Conference of Australia was held in Canberra in 1961, as a predecessor of the Australian Water Resources Council (AWRC), which was established in 1963, after Federal and State Ministers concerned with water resources met in 1962 and made recommendations for its formation. The Underground Water Conference of Austrlia was reconstituted, as well as a comparable Water Resources Conference of Australia, to become technical committees of the AWRC, respectively the Technical Committee on Underground Water (TCUW) (now Groundwater Committee) and the Technical Committee on Surface Water (TCSW) (now Surface Water Committee) (McCutchan, 1972; see also AWRC, 1977a).

TCUW (GC) represents Federal and State groundwater interests and is required to prepare information and advice for the Standing Committee of the AWRC on:

- assessment of the underground water resources of Australia, including reviews of such assessments
- methods and adequacy of data collection and analyses, and means of achieving coordination and uniformity of, and improvement on, methods and techniques.

Following the establishment of AWRC in 1963, the Standing Committee resolved in 1964 that a TCUW Subcommittee of officers from relevant Federal and State authorities should prepare a suitable hydrogeological program for the study of the Great Artesian Basin and a statement on how to implement it, bearing in mind that it would be desirable for the collation of results to be undertaken by BMR. A subcommittee was formed in 1965 which consisted of representatives from Water and Geological Authorities of Queensland, New South Wales, South Australia, the Northern Territory, and BMR. In 1966 this Subcommittee reported on the reasons and recommendations for a hydrogeological study of the Great Artesian Basin with emphasis on: geological mapping, stratigraphic studies, water quality, aquifer characteristics including hydrodynamics, radioactive tracers, and temperature distribution, and a review and assessment of the behaviour of the Basin, including a mathematical model.

The report by the TCUW Subcommittee stated the areas where additional information had to be acquired, and it was decided to defer the review study until the geological mapping was further advanced. Systematic geological mapping of the Basin at a scale of 1:250 000 had started in the 1950's, (and was virtually completed by the early 1970's) and subsurface knowledge increased considerably as a result of seismic and other geophysical surveys, the drilling of several hundred petroleum exploration wells in the 1960's and the gamma-ray logging of water wells. A review of available groundwater data on the Great Artesian Basin had been carried out by Hahn & Fisher (1963).

In 1969 AWRC-TCUW selected BMR to collect and interpret the data on the Great Artesian Basin. In 1970 BMR proposed a study program concerned less with a comprehensive stratigraphical study (because of the progress made in other geological studies of parts of the Basin) than with the use of computers in data processing, storage and retrieval of data, and the modelling of the Basin's hydrodynamics.

The proposal included: preparation of a three-dimensional appreciation of the permeability distribution, ADP (Automatic Data Processing) system for hydraulic and chemical data, preview of model study, study of basin hydraulics, study of groundwater chemistry, age determination and thermal studies, study of recharge areas including geological mapping, shallow drilling, soil moisture, stream-flow studies and watertable fluctuation measurements, and assessment of the basins' groundwater resources and recommendations on their management.

BMR commenced the hydrogeological study of the Great Artesian Basin in 1971. To date (1980) most items in BMR's 1970 proposal have been carried out with the exception of the study of the recharge areas (Habermehl, 1979d, 1980a). No detailed hydrochemical study has been carried out, but a pilot study has begun.

BMR project objectives were to study the hydrogeology of the Great Artesian Basin and to develop and apply a digital computer simulation model. For these purposes geological, geophysical, and hydrological data of the multi-layered confined aquifer system of the Great Artesian Basin from BMR and State geological and water authorities in Queensland, New South Wales, South Australia, and the Northern Territory were collected, interpreted, and combined. An outline of the hydrogeology of the Basin is given in Habermehl (1980a). Processed data are used in the digital computer simulation model GABHYD (Seidel, 1978 a, b, 1980 a, b). This model is based on finite difference approximations and simulates the aquifer geometry in quasi three-dimensional form. The groundwater hydrodynamics of the Great Artesian Basin are simulated, and results of model predictions of future hydraulic behaviour of the Basin are used for regional assessment, planning, and management purposes. Examples of possible future exploitation of the Basin's artesian groundwater resources and their effects are given in Habermehl & Seidel (1979) and Seidel (1980a).

From 1972 to early 1975 the Bureau de Recherches Géologiques et Minières, (BRGM-Australia) under contract to BMR provided staffing assistance to collate, compile, and analyse hydrogeological data. BRGM was also involved in the preparation of data for the model studies and definition of the Basin prototype. BRGM further constructed the mathematical model GABSIM (Ungemach, 1975) which was replaced by the BMR developed model GABHYD during 1975 to 1977.

At BMR, an automatic data processing, storage, and retrieval system was designed to contain the basic data from the Great Artesian Basin. The fixed format of the data base, consisting of thirteen transfer sheets and similar data cards is described in Ungemach & Habermehl (1973).

Hydrological data were obtained from the files and records of the Irrigation and Water Supply Commission (IWSC) (now Water Resources Commission) in Queensland, the Water Conservation and Irrigation Commission (WCIC) (now Water Resources Commission) in New South Wales and the Geological Survey of the Department of Mines in South Australia. These authorities collect and store (ground-) water data of their respective States, and are responsible for the administration and implementation of legislation related to groundwater in the Great Artesian Basin. Government control was implemented in the early 1900s, when the use and control of subsurface water was vested in the Crown, and the State Governments commenced administrative control. State Water Authorities have been collecting information through their licencing systems since that time, have carried out periodic measurements, and undertaken extensive surveys. Records on flowing artesian wells contain the bulk of the available hydrodynamic data; these wells represent the most significant artificial discharge points in the Basin. Non-flowing artesian (generally called sub-artesian) water wells produce much smaller discharges, and information on these wells is generally restricted to basic data about identification, location, and completion details. Information on flowing artesian wells generally consist of registration number and name of well, location, date of drilling and completion, depth, groundsurface level, headwork and casing details, supply and temperature at completion, lithology as described by the driller, depths at which water was encountered and levels to which it rose, the flow it produced, and the results of chemical analysis of the water. Periodic measurements on these wells usually include discharge and pressure measurements, temperature data, and results of chemical analyses. Hydraulic tests carried out on individual flowing artesian wells include constant drawdown (flow recession) tests, recovery (static) tests, and step drawdown (dynamic) tests.

Transcription of data commenced in July 1972 with several technical staff of BRGM working in IWSC-Brisbane and WCIC-Sydney, as well as in Canberra, and was completed in April 1974. Data on nearly all flowing artesian wells was collected and listed on the Master, Well casing and screen, and Aquifer description cards which contain fixed information, and further on the Well discharge, Head and temperature, Hydrodynamics, Pump or flow test and Total dissolved solids cards with contain time variable data. These data form the basis of the Great Artesian Basin (GAB)-ADP data bank from which hydrogeological analysis and most input data for the digital simulation model was prepared.

The data were sorted according to location (State, and 1:250 000 map sheet), identification (well number), and type of data (type of cards), and subsequently checked for logical errors in transcription and punching as described by Krebs (1973). Manipulation of the basic data was carried out by a large set of processing programs, some of which were reported in Krebs (1974). Several other processing programs as well as utility programs are available, but have not been documented. The storage and retrival system of the data was described by Seidel (1973).

Retrieval is carried out by searching map sheet and data card type numbers or codes, and several options for combination of these exist; an additional retrieval procedure can be applied to specify individual well numbers and so facilitate retrieval of information of one or more data card types from a particular well. The problem posed by four sets of sequentially numbered wells in four different States was overcome in the GAB-ADP system by a combination of alpha-numerics which identifies a water well according to the State, 1:250 000 map sheet identification number (these map sheets occupy 1° latitude and 1°30' longitude), and the well registration number. An additional code classifies the wells that have been deepened or reconditioned, and so changed the hydrogeological status.

From 1972 to mid 1974 geological, geophysical, and hydrological data from BMR, State Water Authorities, and State Geological Surveys were compiled, transcribed, and computer processed and stored. Analysis of the hydrogeological information resulted in the definition of a prototype of the Great Artesian Basin (Audibert, 1976; Habermehl, 1980a), which combines the many aquifers in the Mesozoic sedimentary sequence (consisting of continental deposited quartzose sandstones of Triassic, Jurassic, and Cretaceous age) in two confined aquifers, and further two confining beds (Cretaceous mudstone and siltstone) and a near-surface watertable (Fig. 5). The watertable approximates a constant head boundary compared with the changing heads of the confined aquifers.

The prototype forms the link between the real Basin configuration and the computer model. The GABHYD model operates on a square grid with a separation of 25 km between the gridlines; the part of the Great Artesian Basin which was considered fits into a rectangle containing 67 gridlines from west to east and 58 gridlines from south to north. The prototype defines the hydraulic parameters (horizontal transmissitives, vertical leakage factors, storativities) and the state variables (potentials, discharges). For the water table the potentials only are required. Horizontal boundaries of the model are defined as impermeable boundaries or as permeable boundaries defined by prescribed constant potentials. All information is derived from data recorded in the GAB-ADP system.

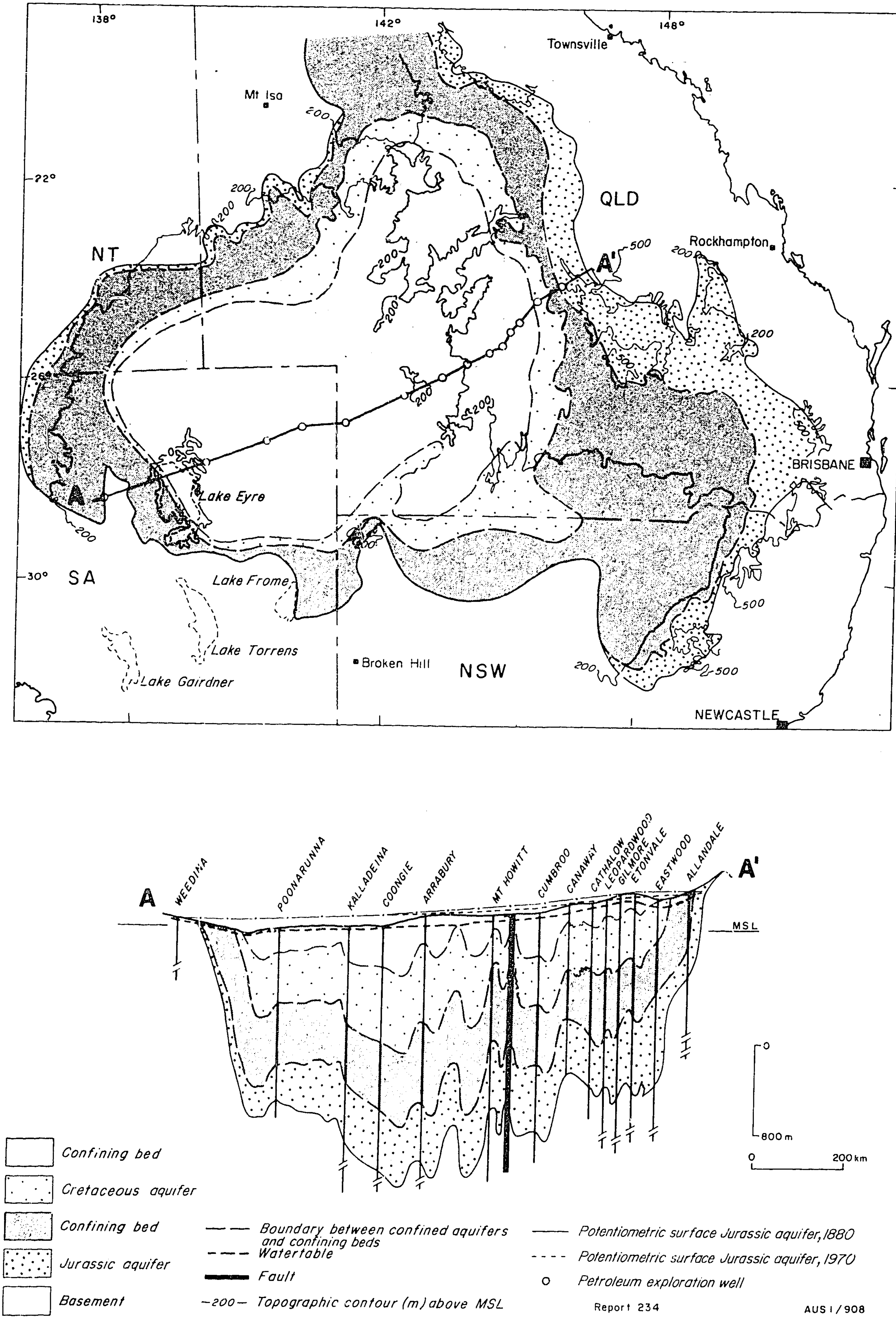

Fig. 5 Lateral extent of the simplified hydrogeological model units and cross-section

The digital computer model GABHYD is based on finite difference approximations of the Hantush approach for leaky aquifers. The model determines for each node of each confined aquifer the complete waterbalance. Model output consists of all potentials and discharges for each major timestep and each gridnode. The GABHYD model consists of a group of computer programs and this program system is used to generate the initial data base, to calibrate the model using a newly developed direct method, run the model over on historic or future exploitation period with different management options, and tabulate and plot the results (Seidel, 1978 a, b, 1980 a, b). Model development commenced in 1975 (to replace the original GABSIM model - Ungemach, 1975) and model calibration was completed during 1977 and 1978, and application runs carried out during 1978.

Confined aquifer CA2 in the model (corresponding with Jurassic aquifers) is the main aquifer of the model. Only a few data are available for confined aquifer CA1 (corresponding with Cretaceous aquifers) and no detailed calibration could be attempted for it. Calibration is by a direct method and directional transmissivities are determined from the recorded potential data and from boundary conditions which include recorded well discharges.

Included in the GABHYD model system are computer terminal operating systems for running the model which are integrated with a terminal operating system to analyse the model output. All stages of the model application from the preparation of input data, including the selected management options, to the analysis and final presentation of results are accessible through the interactive terminal system. Ouput presentation options include: small and large maps produced by line printer, line printer tabulation, contour plot on small or large plotter or photographic film, perspective simulated three-dimensional drawing or contour map drawing on 25-cm or 70-cm line plotters or 35-mm photographic film (Seidel, 1978b).

Application of the model included predictions on continued unchanged development from present artificial discharge conditions (i.e. no new flowing artesian water wells being drilled in the Basin) to the year 2000 (Figs. 6 & 7). Application runs have dealt with results of historical development and with a proposed development in the South Australian part of the Basin (Habermehl & Seidel, 1979; Seidel, 1980a; Armstrong, 1981). Detailed drawdown data against time, the extent of the difference in potentials, and the effects on the immediate area and on other parts of the Basin from 1980 to 2000 can be produced in the form of contour maps at different scales.

BMR organised a workshop to introduce the GABHYD groundwater model of the Great Artesian Basin and its application to potential users (mostly from water authorities in Queensland, New South Wales, and South Australia) in Canberra from 14 to 16 August 1978. It dealt with most of the results of the Great Artesian Basin study, and included: the hydrogeology of the Basin, the model prototype, model discretisation and definition of variables, model calibration, and comparison of calibration results with independent data. Further, a description of the model programs, the running instructions for the model, and output display package was given. During several practical sessions the computer terminal was used to prepare and run the model, including a hypothetical case in South Australia, and to demonstrate and apply the output display package. The workshop was led by M.A. Habermehl and G.E. Seidel of BMR, and ten participants represented the Geological Surveys and Water Authorities of Queensland, New South Wales, South Australia, the Northern Territory, and Victoria.

BMR continues to carry out work on the hydrochemistry of the Great Artesian Basin (Habermehl, 1981).

Results from the hydrogeological study of the Great Artesian Basin led to a theory of hydrocarbon migration under hydrodynamic conditions and entrapment of possible economic hydrocarbon accumulations near faults transverse to groundwater flow in the Eromanga Basin sequence in the central Eromanga Basin area (Senior & Habermehl, 1980 a, b). Senior & Habermehl described the relation between structure, hydrodynamics, and hydrocarbon potential in that part of the Basin. Detailed sampling for chemical analyses, possible hydrocarbon contents and environmental isotopes of flowing artesian water wells in the central part of the Basin was carried out during 1980 to assist studies of possible hydrocarbon migration and stagnation within possible structural and stratigraphic traps in the area and better define hydrodynamic and hydrochemical characteristics (Habermehl, 1980c, 1981).

Aspects of geothermal gradients, as derived from data obtained during the wire-line logging of water wells in the Basin are reported by Polak & Horsfall (1979).

BMR continues to carry out a joint study of the isotope hydrology of the Great Artesian Basin with the Isotope Division of the Australian Atomic Energy Commission begun in 1974. Some aspects of the isotope hydrology of the Basin are reported on in Airey & others (1979).

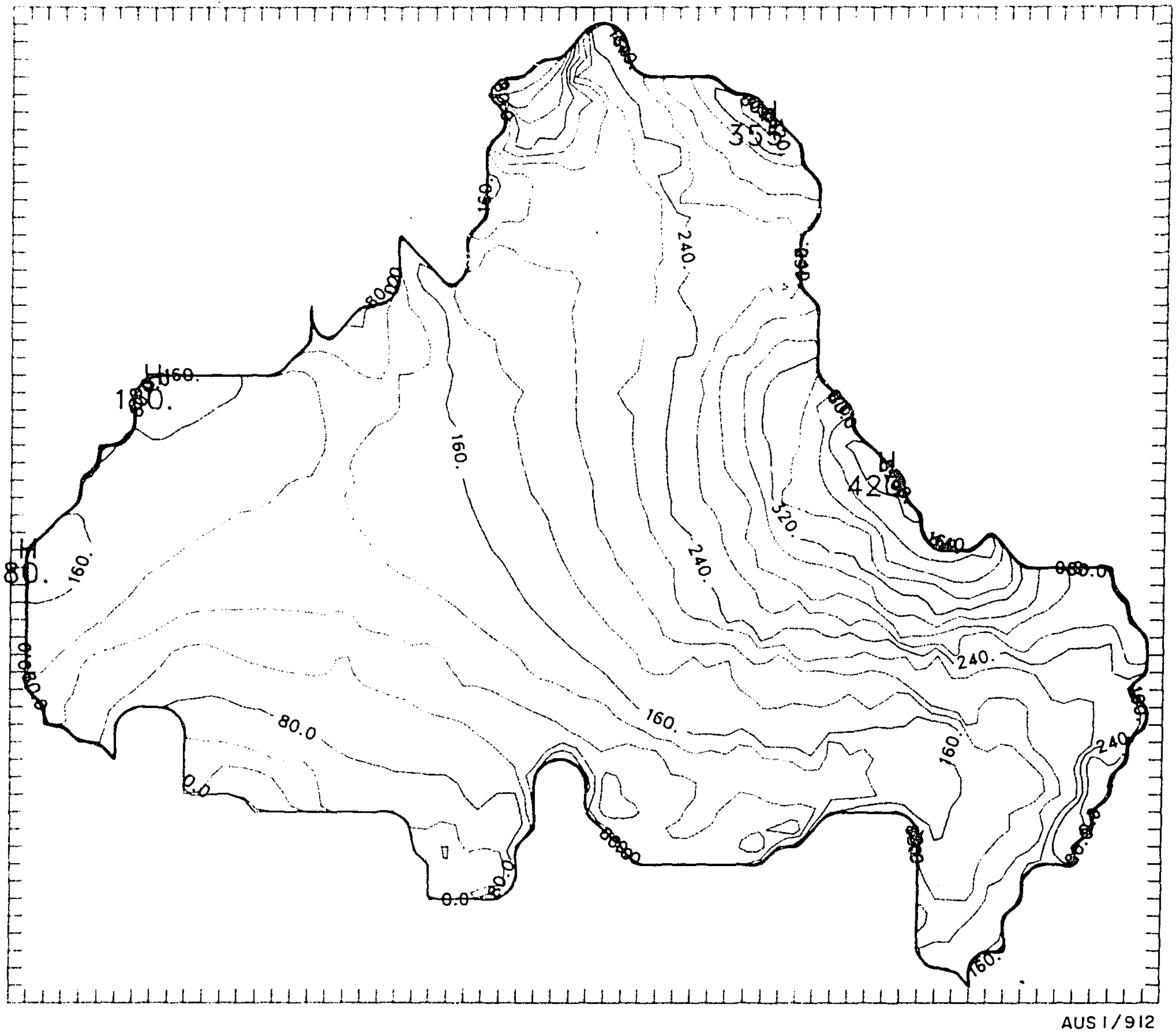

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Fig.6 GABHYD model — predicted potentials for 2000. The area of the Great Artesian Basin studied is indicated in Figure 7. Contours are potentiometric contours (contour interval 20 metres — datum MSL). Each division of the border scale (E-W and N-S) is equivalent to 25 km.

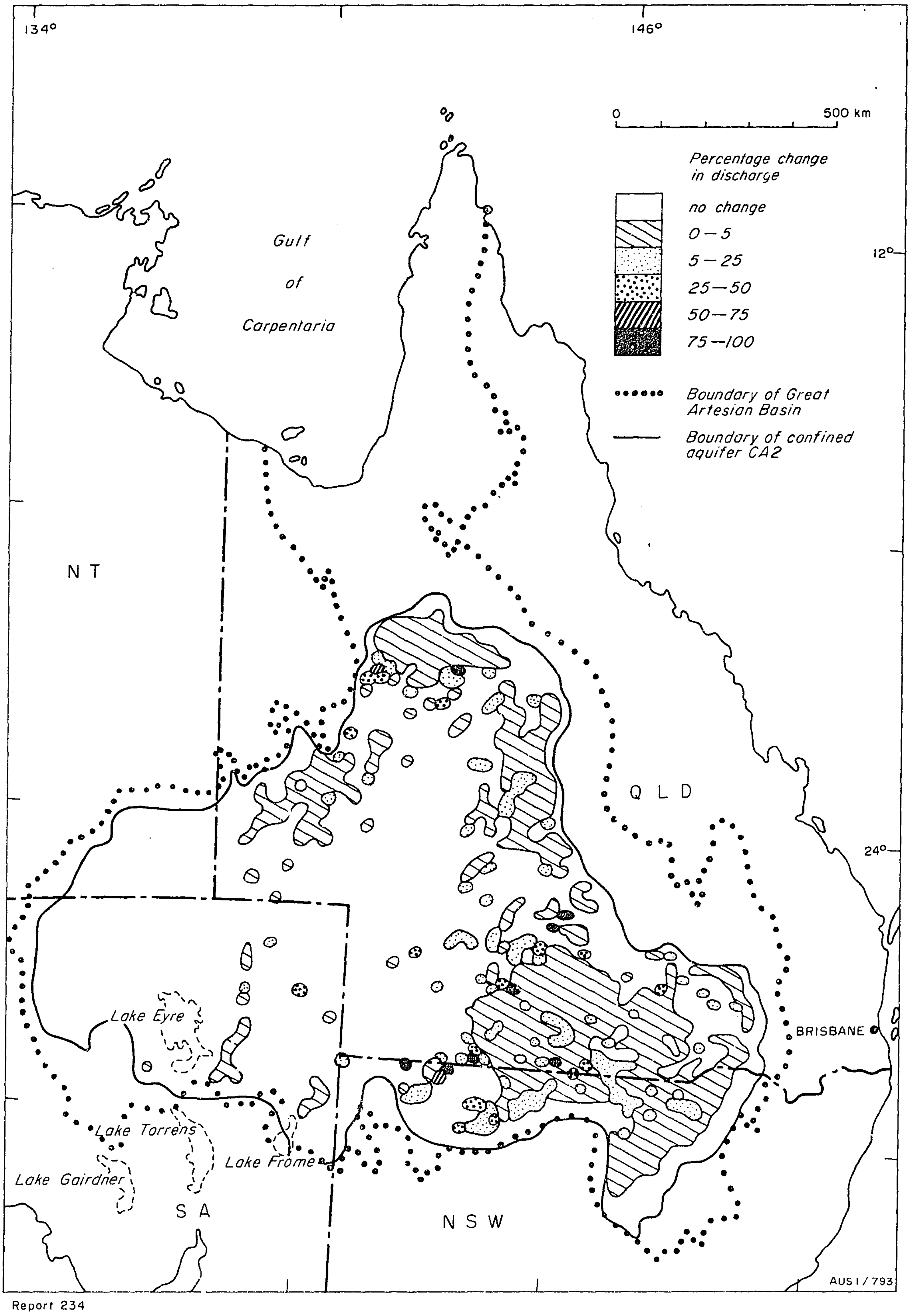

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Fig. 7 Projected percentage change in the discharge of flowing artesian water wells following continued unchanged development during the period 1970 to 2000

Published and unpublished reports resulting from the hydrogeological study of the Great Artesian Basin by BMR from 1971 to 1980 are listed under -

Airey & others (1979), Audibert (1973, 1974, 1975, 1976) Austtralian Water Resources Council (1973, 1974b, 1976c, 1977b, 1979), Exon & Habermehl (1974, 1975), Habermehl (1972 a, b, 1973, 1974, 1975 a,b,c, 1976, 1977, 1978a,b,c,d,e, 1979 a,b,c,d, 1980 a,b,c,d,e, 1981, in prep.), Habermehl & Audibert (1973 a,b, 1974), Habermehl & Morrissey (1980, in prep.), Habermehl & Seidel (1975, 1976, 1977, 1979), Jones (1971), Krebs (1973, 1974), Polali & Horsfall (1979), Seidel (1973, 1977, 1978 a,b, 1980 a,b), Senior & Habermehl (1980 a,b), Ungemach (1975), and Ungemach & Habermehl (1973).

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