*CHAPTER 2*

# WATER — FROM TANK STREAM TO SNOWY SCHEME

**W. H. Williamson**

*"It was by water that all things were constituted; it is water that forms the tender grass and everywhere diffuses life, and it is from heaven that the sweet rains fall; and this rain is everywhere the same, but its fruits are varied."*

—St. Cyril of Jerusalem, 4th Century A.D.

## The Beginnings

"If any person whatever is detected in throwing any filth into the stream of fresh water, cleaning fish, washing, erecting pig-sties near it, or taking water but at the tanks, on conviction before a magistrate, their houses will be taken down and forfeit £5 for each offence to the Orphan Fund." So read a General Order issued on October 14, 1802, to the inhabitants of early Sydney. It referred to the new colony's first water supply, "the finest spring of water" which had led Captain Arthur Phillip to choose Sydney Cove as the site for his settlement in 1788.

Draining a marshy area of less than 180 acres on the western slopes of what is now Hyde Park, the stream was naturally subject to poor flows in dry seasons. Two years after the foundation of the settlement, tanks were cut into the flanking sandstones near the present Spring and Bond Streets, and it became known as the Tank Stream.

The settlers were soon brought face to face with the harshness of their new environment. Recurrent droughts caused severe shortages of water, and it is rather remarkable that the Tank Stream served as Sydney's main source of water for almost 40 years, being finally abandoned in about 1826. However, long before this, many settlers had constructed their own wells, and water was also being carted from the Lachlan Swamps in what is now Centennial Park.

It was in 1826, too, that John Busby reported in favour of the Lachlan Swamps being Sydney's next water supply source, and the following year saw the commencement by convicts of a 12,000-foot-long tunnel from Hyde Park to the Swamps—the so-called Busby's Bore. The tunnel was not completed till 1837, but, fortunately, by 1830, the rocks being penetrated were yielding sufficient groundwater to the tunnel to provide a useful supply.[1]

[1] Aird, W. V., 1961, "The Water Supply, Sewerage and Drainage of Sydney", Halstead Press, Sydney.

Following the incorporation of Sydney as a city in 1842, the Municipal Council became responsible for water supply, sewerage and stormwater drainage, and, by 1844, had installed pipes from Busby's tunnel to give Sydney its first reticulated water supply. However, it was not until the Botany Swamps Water Supply Scheme was completed in 1859 that Sydney had a reasonably substantial source of water. This scheme involved pumping from a low dam (the "Engine Pond") built by convicts across the swamps near Botany Bay in 1838, and was not superseded till 1886. (With regard to the operation of this scheme, Aird (1961) records the rather droll, but nonetheless practical, method of overcoming the lack of telegraphic or telephonic communication in those days. A stand-pipe was erected near Victoria Barracks, with its top at the same level as the top water level of the reservoir at Paddington. The stand-pipe was watched through a telescope from the Botany pumping-station, and when it overflowed, thus indicating the reservoir to be filled, the pumps were stopped.)

This was the pattern associated with the growing pains of Sydney—rapidly increasing population and recurrent droughts causing a constant demand for larger and more reliable water supplies, factors not unfamiliar to present-day planners.

In the meantime, with the crossing of the Blue Mountains by Blaxland, Lawson and Wentworth in 1813, the young colony was finally able to burst its bonds. Governor Macquarie rapidly followed up the discovery by founding and issuing instructions for the laying out of Bathurst in 1815. In extending exploration from the original point of termination of Blaxland's expedition in the Cox's River Valley, Surveyor Evans, late in 1813, crossed the Great Dividing Range, discovered and named the Fish and Macquarie Rivers, and followed the latter to a point 42 miles beyond Bathurst. Then, in 1815, during the Governor's stay to found Bathurst, he explored south-west to discover the Lachlan River and trace its course to Mandagery Creek confluence. He saw, by its direction, that it could not possibly flow into the Macquarie. Thus arose the problem of the inland rivers—whence did they flow? It was not until 1844, after a series of important explorations by men such as Oxley, Hume, Ovens, Hovell, Cunningham, Sturt and Mitchell, that Sturt solved this question by tracing the Darling River upstream from its confluence with the Murray to a point near Menindee which Mitchell had reached from the opposite direction in July, 1835.

It is interesting to note the different conditions encountered during these early explorations. After being frustratingly stopped by extensive marshes in the lower Lachlan in 1817, Oxley concluded that the Lachlan terminated in a vast shallow inland sea which was uninhabitable. The following year he was again stopped by marshes, this time on the Macquarie. In contrast, in 1828, during one of the most severe droughts the colony had experienced, Sturt and Hume found only weeds in the Macquarie Marshes, and when they pressed on and discovered the Darling River it was too salt to drink. Sturt reported settlement in this area to be hopeless, but when, in the same area, Mitchell followed the Darling for some 300 miles in 1835, it was full and fresh. Later that year he was to find Oxley's Lachlan Swamps to be completely devoid of water, and he was therefore able to follow the Lachlan River to its junction with the Murrumbidgee after skirting the Great Cumbung Swamp at that point. Little wonder the authorities received conflicting reports!

With a rapidly expanding wool industry, and the need for more and better pasture land, settlers eagerly followed up the discoveries of the early explorers, and quickly spread through the State. However, in terms of population increase, the importance of the gold-rush, starting with Hargraves' announcement of payable gold in 1851, can hardly be over-rated. In the years from 1850 to 1856, the population of the Australian colonies leapt from 426,694 to 928,874. With the increase in population, enterprise quickened in every direction. At this time too, railways developed, as well as telegraph and steamship communication with England. It was a booming colony, then, when, in 1866, the Royal Charter was granted to the Royal Society of New South Wales, but one in which there was already considerable concern about water resources and the need for conservation measures.

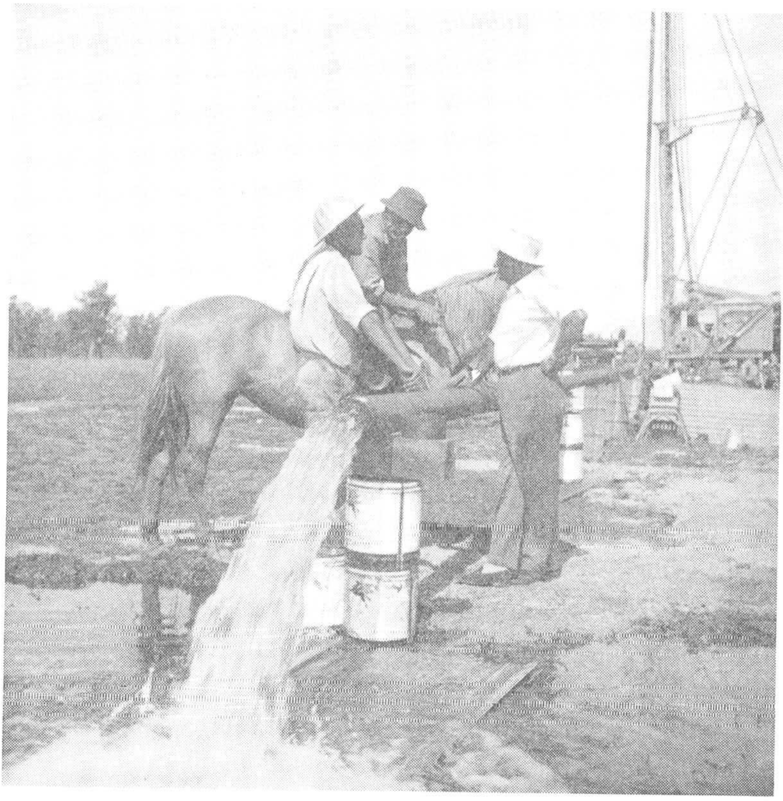
The year 1866 was also notable from the water viewpoint in that pioneer water-conservation water-works were commenced by the Government expending £2,900 on the sinking of wells to render practicable the route from the Darling to the Lachlan and Warrego Rivers. Considerable attention was subsequently given to developing the western stock routes, and by 1884, some £115,000 had been spent on the construction of excavated tanks, dams, and wells for this purpose.

## Discovery of the Great Artesian Basin

Within the latter period, too, a tremendous fillip was given to the search for adequate water supplies in western New South Wales by the discovery of artesian water. Scientists of the day had already been pondering on the fate of the water disappearing from the Murray-Darling system. Rawlinson[2] had appealed for an inquiry "into the cause of the disappearance of the vast bodies of river water which collect on the inner water-shed of the coast ranges of Australia" and

[2] Rawlinson, T. E., 1878, "Subterranean Water Supply in the Interior" (abridged), *Trans. Philosophical Society,* Adelaide, South Australia, p. 124-126.

considered that the interior of Australia would "ultimately be proved to be the storage reservoir where are conserved the rain and river waters which other theories fail to account for". Government Astronomer Russell (1879)[3] claimed that less than $1\frac{1}{2}\%$ of the rain falling in the upper Darling River catchment flowed past Bourke, whereas for a corresponding point on the Murray, the discharge appeared to be of the order of 25% of the catchment rainfall. In the same year, Professor



Ten-inch diameter bore, 350 ft. deep, located in Lachlan Valley, being tested at 40,000 g.p.h. The bore could yield 100,000 g.p.h. Constructed by Water Conservation and Irrigation Commission. (See page 97.)
(Photo: Water Conservation and Irrigation Commission)

Tate examined mound springs near Lake Eyre, South Australia, pronouncing them to be natural artesian wells and predicting that boring for artesian water would be successful. These speculations were soon answered, for Mr. David Brown, manager of Kallara Station, finding the supply obtained by reconditioning an old 110-foot well to

[3] Russell, H. C., 1879, "The River Darling—the waters which should pass through it", *Jour. Roy. Soc.*, XIII, p. 169-170.

be inadequate, bored on from the well-bottom with a four-inch diameter "Wright and Edwards water auger", and at 144 feet obtained a flowing supply—the first flowing bore in what was to prove to be the world's largest artesian basin, the Great Artesian Basin. The bore (actually five were put down in close proximity to each other because they kept choking with sand) was subsequently known as Kallara No. 1 or Wee Wattah Bore, and is about 18 miles from the Darling River and some 105 miles W.S.W. from Bourke. It was also only about six chains west of Wee Wattah mud springs, which were no doubt due to the shallow artesian conditions in the area.

There is some confusion in the literature as to the date of construction of this bore. The most pertinent evidence coming under the notice of the author is the minutes of evidence by Mr. David Brown in the Third Report of the Royal Commission on the Conservation of Water (1887). In describing the reconditioning of a well sunk in about 1864, he stated (p. 51): "I began to work at that shaft in 1878; it was filled up to within 70 feet of the surface. I sent a man down to clean it out, and he sent up sand and then big boulders of hard clay. He said the shaft was sound all the way up, which struck me as peculiar because these lumps weighed several hundredweight when unbroken, and were surrounded by a sound shaft. Evidently this had been sent up the shaft by a burst of water much stronger than anything we were dealing with. The supply was about 500 gallons per day. After sinking as far as possible, we started boring and got a considerable supply, equal to about 120,000 gallons per day. But a large quantity of sand came up with the water and continually choked the bore." Consequently, since the work involved in reconditioning the well and augering 34 feet from the bottom would not take a great deal of time, it would appear that the flow was obtained in 1878 or possibly 1879. (It may be noted that this was not the first artesian bore in Australia, for a flowing supply was obtained from a 171 feet bore near Perth, Western Australia, in 1871. The first attempt to bore for artesian water in Australia had the object of augmenting Sydney's water supply. The bore was commenced within the walls of Darlinghurst gaol in 1851, but was abandoned at 75 feet, owing to sabotage.[4])

The finding of shallow artesian water on Kallara Station encouraged deeper exploration, and within a few years, large artesian flows were being obtained from bores over 1,000 feet deep, the first of these being in 1887, on Kerribree Station, about 50 miles W.N.W. of Bourke. By 1884, with the introduction of the Public Watering-places Act, the Government was inviting tenders for the construction

[4] Pittman, E. R., 1901, "The Mineral Resources of N.S.W.", Government Printer, Sydney.

of artesian bores on some of the far-western stock routes, and the successful completion of many of these provided safe and permanent water supplies on stock routes which in some cases could previously be little used. Development was further promoted by the Artesian Wells Act in 1897, which enabled groups of settlers to obtain Government assistance to construct an artesian bore to serve their collective properties, the water being distributed to them by open drains. However, it was not until the Water and Drainage Act of 1902 that provision was made for constituting Bore Trusts to administer the respective bores.

During these early years of development in the Great Artesian Basin, the geologists of the various State Geological Surveys were mapping large areas of country, assessing the new information rapidly coming to light, and advising on the prospects of boring in various areas. Notable in New South Wales were Wilkinson, Pittman and David, as may be seen from their writings in the Annual Reports of the Department of Mines, and in the Journals of the Royal Society of New South Wales. It is a tribute to the zeal of the geologists of the day that, in spite of the enormous size of the Basin (some 670,000 square miles, of which about 80,000 are in New South Wales), its limits were broadly established by about 1900. It is indeed fortunate that geological conditions have provided this water-source in regions in which rainfall is often so low and unreliable that otherwise the pastoral industry would be impracticable.

## Water Supply Problems Extend

While such inland developments were going on, Sydney and other parts of the State were not without water supply problems. Fears of the supply from Botany being inadequate for the rapidly-increasing population of Sydney led to the appointment of a Royal Commission in 1867. Although the Commission recommended a scheme of supply from the Upper Nepean River in 1869, work was not commenced until 1880 and water from the scheme was not available until 1886. The control of Sydney's water supply was taken over by the Metropolitan Board of Water Supply and Sewerage in 1888, with the Public Works Department the constructing authority, a situation which was remain until the present Metropolitan Water Sewerage and Drainage Board was constituted in 1925, and became its own constructing authority.

However, concern over water supply and the need for conservation measures extended far beyond Sydney, and in 1884, a Royal Commission was appointed under Mr. (later Sir) William Lyne "to make a diligent and full enquiry into the best method of conserving the rainfall, and of searching for and developing the underground reservoirs supposed to exist in the interior of this Colony, and also into the practicability, by a general system of water conservation and distribution, of averting the disastrous consequences of the periodical droughts to which the colony is from time to time subject". The Commission was extant for four years, and its lengthy hearings were published in three reports, in 1885, 1886 and 1887, respectively, but it failed to achieve much direct action.

The second report (1886) deals mainly with conferences with a Victorian Royal Commission on Water Supply, but gives an interesting insight into conditions in New South Wales in deploring the fact that large cities such as Bathurst, Goulburn, Maitland and Newcastle "have for many years been without a water supply". The report goes on to state: "It is hardly conceivable that in any part of the globe the natural conditions of life can be more favourable to health than in the salubrious climate of this Colony; and yet, owing as we believe, to neglect in providing a supply of pure water, both in the towns and in the rural districts, typhoid fever and other diseases have increased to an abnormal and alarming extent." (In the latter context, some of the early water analyses by the Government Analyst's Branch for the then Board of Health appear ominous, e.g., the description of a sample of water from Shea's Creek, Waterloo, in September, 1889, reads: "Appearance—filthy; Odour—unbearable." (Personal communication, Dr. T. Rennie, Department Public Health.).)

The first and third reports of the Commission (1885, 1887) include the minutes of evidence given by numerous witnesses, mostly interested landholders. Notable among the scientific witnesses called were Government Astronomer H. C. Russell (then responsible for meteorological work) regarding rainfall, evaporation, and stream flow, and Government Geologist C. S. Wilkinson, who gave a treatise on the geological factors affecting groundwater occurrence.

The most tangible outcome of the Royal Commission was the establishment of a Water Conservation and Irrigation Branch, initially attached to the Department of Mines and Agriculture but later (1896) transferred to the Public Works Department. The Commission's enthusiastic engineer, H. G. McKinney, was appointed to direct the Branch. In 1885, he had initiated stream discharge measurements in New South Wales, organizing a programme of gauging the important rivers of the colony. Stream-level measurements (as distinct from stream-flow or discharge measurements) had been commenced on the Murray River by the Victorian Government in 1865, in the form of daily levels at Echuca and Mildura, whilst in 1879, Government Astronomer Russell established eleven gauges in the Murray drainage system (five on the Darling, three on the Murrumbidgee and three on the Murray), and published diagrams showing the height of river level "above summer level".

McKinney also began engineering investigations on the Murrumbidgee River, and in his first annual report (1891) recommended the construction of three irrigation canals from the river. No action was taken on the recommendations, but in 1896 the Government invited retired Colonel F. J. Home, an irrigation expert from India, to report on the prospects of irrigation and water conservation in New South Wales, and in his report (1897) he devoted particular attention to McKinney's proposals.

Home briefly dismissed the coastal river basins as being of little consequence for irrigation on a scale requiring Government action, and concentrated on the inland drainage systems. After reviewing these he concluded that only the Murray and Murrumbidgee Rivers lent themselves to major irrigation schemes, the flows in the other major rivers being too irregular and sites for adequate storage of water at reasonable cost being extremely rare. He endorsed schemes proposed by McKinney for canals from the two rivers, but amended the location for the off-take from the Murrumbidgee and considered storage reservoirs essential for both schemes. Of the two rivers, he favoured the Murrumbidgee because of "the facility with which water can be brought to the surface of the country and the small rainfall of the tract commanded" and also pointed out that it had "the advantage of being entirely within the limits of the Colony". Consequently, he recommended that the scheme on the latter be fully investigated, and further, stated that if it were considered "sufficiently promising to warrant its being undertaken, it would appear desirable to allow the irrigation to develop itself before taking up the investigation of the Murray canal project". He added a note of warning too, "irrigation is a new industry here, and a little caution in expanding it can do no harm, and may save a good deal of money and trouble", words which were to prove rather prophetic.

At this stage, Victoria was well ahead of New South Wales in the irrigation field, having commenced projects in the early 1870's.[5] Attempts had been made to establish projects in New South Wales, but they were more or less abortive, apparently because of poor organization and public apathy. The earliest of these was at Wentworth where, on September 1, 1890, the Wentworth Municipal Council was constituted an irrigation trust and endowed with control of the temporary common, an area of 10,000 acres, and given authority to pump from the Murray and Darling Rivers. However, in spite of

[5] Eaton, J. H. O., 1945, "A Short History of the River Murray Works", Government Printer, Adelaide.

attempts by public advertisements to induce settlement, only about 400 acres had been leased by 1906 (Report of Parliamentary Standing Committee on Public Works, Barren Jack Storage Reservoir, 1906). Similarly, the Hay Irrigation Trust, proclaimed in 1892, vested 17,147 acres in the Hay Municipal Council to establish works for water conservation and irrigation, and to lease such lands. In 1895, the area vested was reduced to 4,400 acres, but by 1902 only 800 acres had been taken up, of which about 600 acres were being irrigated, the water being drawn from the Murrumbidgee. A like scheme for 2,000 acres at Balranald, in 1893, had an even more ignominious outcome, only 60 acres having been leased by 1906.

With an apparently inexhaustible supply of water issuing from artesian bores, attention was also given to the possibility of utilizing such bores for irrigation projects. The first experiment was on 20 acres at Native Dog Bore, constructed in 1891 about 45 miles from Bourke. Then, at Pera Bore (completed in 1894), near Bourke, 640 acres were subdivided into 20-acre blocks as an irrigation settlement and 50 acres set apart as a Government Experimental Farm. Home reported[6] that eleven of the blocks had been taken up at a rental of five shillings per acre per year for land and water, and "some of the lessees were doing well". Home considered that sinking artesian bores specifically for irrigation purposes would not be warranted for some time to come, and that the cost of obtaining the water was such that the irrigation of ordinary crops would not be remunerative. It is apparent that even then difficulties were being experienced in irrigating with the water, for he stated: "As the soil cakes on the surface after irrigation, and the water from this and all other bores contains alkali, the necessity for keeping the surface broken up and for using the water sparingly is obvious."

The alkali problem proved to be the undoing of the Pera Bore irrigation scheme, and is the reason for the Artesian Basin waters being generally unsuitable for irrigation purposes. Even though the total saline content of the water is not unduly high, the salts present are mainly sodium salts, and the unfavourably high ratio of sodium to calcium plus magnesium ions has an adverse effect on soil structure, ultimately rendering the soil impervious. Nevertheless, for some fourteen years, orchards were irrigated from Pera Bore and Symmonds (1912) stated that "the Pera oranges have a world-wide reputation for both flavour and size, some of them realizing fancy prices, such as 7½d. each. . .". He details considerable experimentation with gypsum and nitric acid to try to offset the ill-effects of the alkali, but an economic

[6] Home, F. J., 1897, "Report on the Prospects of Irrigation and Water Conservation in New South Wales", Government Printer, Sydney.

and practicable solution to the problem was not forthcoming and the irrigation scheme abandoned soon after. An experimental farm set up to use artesian water at Moree during the same period suffered a similar fate, though the black soils, being lime-rich, initially gave excellent results. It was evident then that, although of paramount importance to pastoralists, the waters of the Great Artesian Basin could not be of consequence in irrigation development.

In the meantime, following on Colonel Home's recommendations, McKinney investigated various storage sites on the Murrumbidgee and selected one near Barren Jack Mountain as being the most favourable. However, again, no action was forthcoming.

Matters were finally brought to a head because of the continuation of a series of drought years, the period from 1895 to 1902 being now considered to be the most severe drought ever recorded in New South Wales (Current Affairs Bulletin, 1966). Agitation by landholders for irrigation and stock water schemes became so intense that a conference convened in 1902 at Corowa by a local body, the Murray River Main Canal League, gained the attendance of the Prime Minister of the Commonwealth and the Premiers of New South Wales, Victoria and South Australia. As a result of resolution passed at the conference, a Royal Commission was appointed the same year to report and make recommendations on the conservation and distribution of the waters of the Murray River basin (Interstate Royal Commission on the River Murray, 1902).

This was the first Commission in which the three States concerned with the River Murray were brought together. Previous interstate conferences, dating as far back as 1863, and Royal Commissions involving individual States, had failed to arrive at any agreement satisfactory to the three. At this stage, the attitude of New South Wales and Victoria was that where the Murray formed their boundary it could be developed by agreement between them, irrespective of the claims of South Australia, and any tributaries (such as the Murrumbidgee) were the sole property of the respective colony. South Australia was naturally violently opposed to such views, and, furthermore, was particularly anxious that sufficient water be maintained in the river to allow navigation. While it was not to be until 1914 that agreement on the Murray was finally reached, the machinery was at last in motion.

## Development in the Murrumbidgee Valley

The evidence given to the 1902 Commission by the three States reflected rather badly on New South Wales for its almost negligible achievements in irrigation development. More had been achieved privately by Sir Samuel McCaughey, who had constructed some sixty miles of channels and was irrigating over 2,000 acres of crops and pasture on his North Yanco property, and no doubt his evidence and example spurred on action in New South Wales. (Sir Samuel appears to have been carried away with his enthusiasm for irrigation. His misleading claims of low water requirements and very high yields, given to the Commission and to a Public Works Committee in 1906, were later to be used as evidence of false pretences in attracting settlers to the Murrumbidgee Irrigation Area.)[7] The following year, and again in 1905, Mr. Robert Gibson approached Parliament with a definite proposal, promoting the Murrumbidgee Northern Water Supply and Irrigation Bill, a scheme to establish irrigation and water supply for districts between the Lachlan and Murrumbidgee Rivers by means of a dam near Barren Jack Mountain, a weir on the Murrumbidgee 19 miles upstream of Narrandera, and a canal and subsidiary works from the river at Narrandera (Cyclopaedia of New South Wales, 1907). Although Gibson's scheme was subsequently amended in several important respects, mainly regarding the reservoir and weir, it provided the initial proposal for the Murrumbidgee irrigation scheme.

The scheme finally adopted was that recommended by Public Works Department engineer L. A. B. Wade, who, in 1905, had been deputed to investigate the lands adjoining the river with regard to their suitability for irrigation. (It is of interest that he reported the best lands to be on the northern side of the river, whereas Colonel Home favoured the southern side.) Following approval of Wade's scheme by the Public Works Committee in October, 1906, the "Barren Jack Dam and Murrumbidgee Canals Construction Act, 1906" was passed shortly afterwards, with the Public Works Department to be the constructing authority. Little time was lost in proceeding with the various works and rapid progress was made.

Land resumption was authorized by the Murrumbidgee Resumption Act and the Murrumbidgee Irrigation Act (1910), and the latter made provision for the scheme to be administered by a Trust consisting of the Secretary for Public Works, the Secretary for Lands and the Minister for Agriculture. However, the latter Act was repealed and replaced by the Irrigation Act, 1912, the basis of subsequent legislation for the scheme. This dispensed with the Trust and appointed a Commissioner for Water Conservation and Irrigation, the first of whom was Mr. L. A. B. Wade. The new Commission, which commenced operations in January, 1913, was set up to administer and control all water conservation and irrigation projects for rural purposes in New

[7] Langford-Smith, T., 1966, "Murrumbidgee Irrigation Settlement. A Study of Irrigation Planning, Establishment and Growth", Part 1 of "Water and Land", Aust. National University Press, Canberra.

South Wales, and the Commissioner had extremely wide powers. (In 1916, the Commission was reconstituted to provide for three Commissioners, with the Minister for Agriculture as Chairman, a situation which was to remain until 1949, when the Conservation Authority of New South Wales Act provided for three independent Commissioners under the Minister for Conservation.)

Resumption of land commenced in June, 1911 (the first being 68,000 acres of Sir Samuel McCaughey's estate) and two irrigation areas, Yanco and Mirrool, were planned to be centred on town sites for Leeton and Griffith, respectively. Progress with Burrinjuck Dam and other phases of the scheme were such that the first water for irrigation was supplied to Yanco on July 13, 1912, at the official opening of the Murrumbidgee Irrigation Areas. The Mirrool Area was soon to follow, and received its first water in October, 1913. Owing to the intervention of World War I, and other factors, the dam was not completed till 1928.

It was not long before problems began to appear. In a new and rapidly prepared scheme, these were naturally many and varied. However, the main initial difficulties related to block sizes being too small, soil type in some areas being unsuitable for the purpose proposed, and settlers often being unsuitably qualified (e.g., by November, 1913, 20% of the settlers were ex-Broken Hill miners). Langford-Smith (1966)[8] has provided a valuable detailed study of the development of the Murrumbidgee Irrigation Areas and of the many problems and issues resolved over the years. Apart from economic aspects, his study illustrates the absolute necessity for the integration of engineering and science to implement and operate such irrigation projects.

With regard to early errors in planning, Langford-Smith is critical of the scheme being "regarded essentially as an engineering undertaking", pointing out that "practically the whole of the early planning was carried out by the engineers, including the choice of lands suitable for irrigation farming". He concedes that soil science was practically non-existent in Australia at this time, but cannot account for the apparent lack of investigation of the water-table situation and the dangers of water-logging and salination of soils, since such problems had long been experienced in irrigation projects in other countries. From the agricultural side, some provision was made by setting up the Yanco Experiment Farm in 1909, but he considers this to have been too late to obtain adequate information to advise on crops for the area.

The problems of block size and soil suitability have gradually been overcome, the former by increasing acreages and the latter by

[8] *Ibid.*

adjusting the land use to crops or pursuits appropriate to the particular soils. In the latter regard, an important development in the use of some of the heavier soils was the introduction of rice. From an experimental planting of 157 acres in 1924, production increased until by 1928 the Murrumbidgee Irrigation Areas were supplying the bulk of Australia's requirements. Today it is by far the most valuable single crop or product from the Areas.

The problems of water-logging and soil salination are almost inevitably associated with large-scale irrigation projects, simply because the disturbance of the natural hydrologic balance leads to the raising of the water-table within the area. Although recognized as a danger some years earlier, the first incidence of widespread water-logging occurred in 1931 due to the aggravation of the heavy summer rains of 1930. This was to be the pattern in subsequent wet seasons, such as in 1939, 1942 and 1956, and heavy damage resulted in horticultural areas. (Because of its heavy water requirements, some 6 acre feet per year, rice also creates a problem but this is overcome by segregating rice areas from horticulture. Difficulties also occur with vegetable growing in horticultural areas, a factor which became evident during World War II when enormous quantities were grown for the Allied Services.) The initial occurrence caused the Water Conservation and Irrigation Commission (hereinafter referred to as W.C. & I.C.) to set up a special Research Branch in 1931 to commence immediately on a long-term programme of investigation, including test-boring to determine the nature and sequence of deeper strata, systematic checks on water level behaviour throughout the Areas, and methods of improving drainage. Tile drainage, although expensive, has been found the most effective means of coping with the water-logging of horticultural lands, and it is significant that most of the farms tile-drained prior to 1956, the worst year, suffered little damage. Experiments on the use of tube-well drainage, i.e., inducing soil drainage by pumping from bores tapping underlying aquifers, were commenced in 1945, and this method has proved successful in some areas.[9]

The lessons learned over the years have been well taken, and the Irrigation Areas are now befittingly well served by scientific research establishments and extension services. Hydrological problems incurred in the operation of the Areas are dealt with by the Research Branch of the W.C. & I.C., and a wide range of problems and aspects appropriate to irrigation areas are covered by the Irrigation Research Station. The latter was initiated in 1926 when the Citrus Research Station, which had been established two years previously, was taken over and its

[9] England, H. N., 1964, "Problems of Irrigated Areas", Paper C11 in "Water Resources, Use and Management", Melbourne University Press.

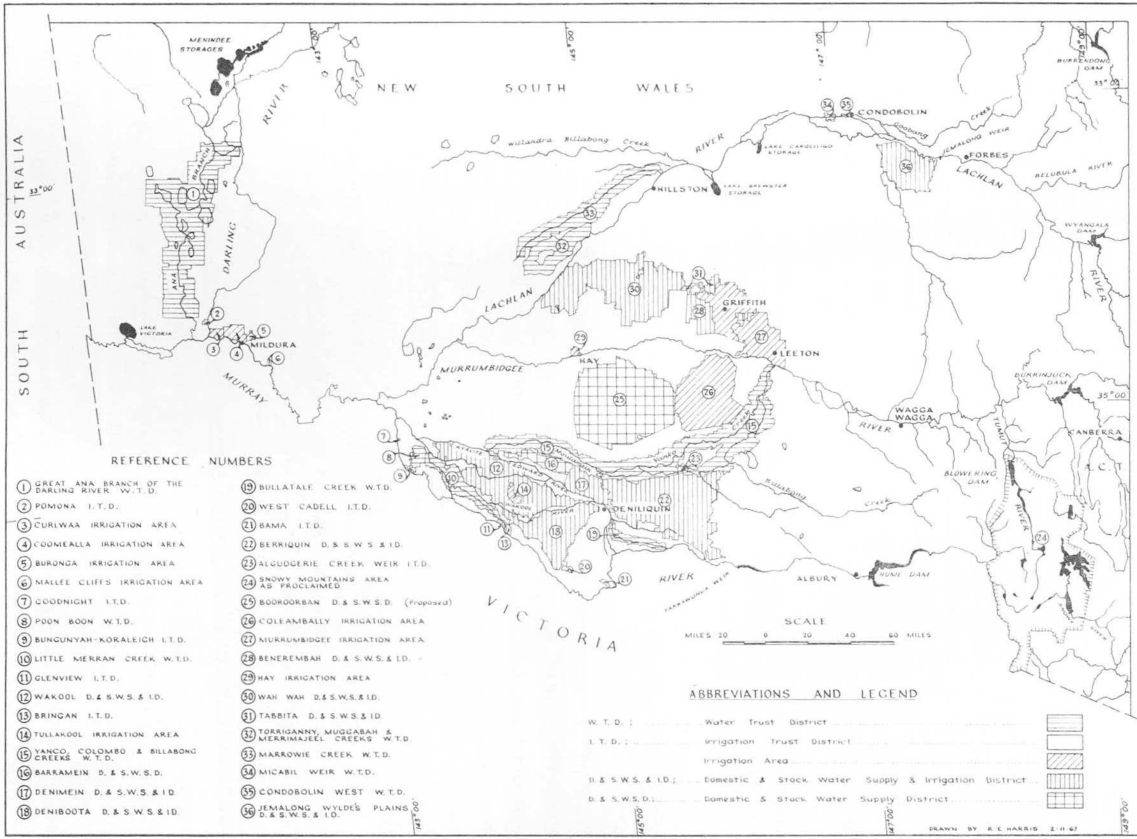
activities expanded by the Commonwealth Council for Scientific and Industrial Research (now C.S.I.R.O.). In addition, there are the Yanco Experiment Farm (recommenced in 1945 after ceasing operations in 1928), an extension organization of various authorities known as the Irrigation Research Extension Committee, and the M.I.A. Agricultural Service of the Department of Agriculture.

As development proceeded in the Murrumbidgee, provisions were also made for channel reticulation of water for less intensive use than is required for the Irrigation Areas. These are the Water Trust Districts and the Irrigation Districts, which have proved to be of enormous benefit in allowing more efficient land use and increased productivity. Water Trust Districts do not involve any change of land ownership, and water is provided only for stock and domestic purposes. The first of these was the Yanco-Colombo-Billabong Creeks Water Trust, constituted in 1921 and serving an important sheep area. Gunbar Water Trust District, embracing over half a million acres, was set up in 1930, but has since been converted to an Irrigation District (Wah Wah).

Irrigation Districts (more properly, "Domestic and Stock Water Supply and Irrigation Districts") are directly controlled by the W.C. & I.C., as opposed to Water Trusts in which the Trust comprises representatives of the landholders and the Government, the former in the majority. However, again they involve no change of land ownership. They have the important advantage of allowing irrigation, mostly of pastures, but also crops, including rice in some cases, e.g., in Benerembah District. Irrigation Districts were commenced with Tabbita in 1935, and Benerembah the following year.

Development is still proceeding along the Murrumbidgee. The latest project is the Coleambally Irrigation Area, the first stage of which is currently being settled. (As at June 30, 1966, 194 large area farms and 14 horticultural farms had been taken up and the value of the year's production was $3,530,506 (W.C. & I.C. Annual Report, 1966).) This Area has had the benefit of the hard-earned experience gained from previous developments on the Murrumbidgee and should be able to avoid the pitfalls. It has been carefully investigated and planned (including its own township) and adequate provision has been made to allow for diversification of production. Full development of the area is dependent on water from Blowering Dam, now under construction for the Snowy Mountains Hydro-Electric Authority.

Sixty years ago, probably not more than 100 people earned a living from the land now occupied by the Murrumbidgee Irrigation Areas and associated districts, and they were harassed by droughts. To-day, these lands support a population of over 30,000, and the value




Surface Water Developments in south-western N.S.W.

of production in 1966 was $27,970,413, the seventh successive record year (W.C. & I.C. Annual Report, 1966). They must surely stand as a monument to man's enterprise and his ability to cope with an adverse environment.

## Development in the Murray Valley

Whilst the Interstate Royal Commission of 1902 appears to have sparked action towards setting up the Murrumbidgee Irrigation Areas, its prime concern was the interstate issues involved in the use and control of the River Murray waters. It was readily conceded that an agreement had to be reached, but the issues were so complex and contentious that deriving a formula acceptable to the three States took a considerable time. After a series of Premiers' Conferences, an agreement was signed in 1906, which, *inter alia,* made provision for a River Murray Commission of three members, one from each State, but it was not ratified by any of the State Parliaments (Eaton, 1945).[10] Negotiations continued between the States, and in 1911 a Premiers' Conference agreed that engineers of the three States be instructed to make an inquiry and to report and make such recommendations which they considered "essential or conducive to a settlement by agreement between the States of New South Wales, Victoria and South Australia, of the question of the River Murray and its tributaries". Following investigations, including the study of new and more complete stream gaugings than had previously been available, an Interstate Conference of Engineers in 1913 submitted a report which formed the basis of the River Murray Agreement of 1914. This was then incorporated in the River Murray Waters Act, passed by the Commonwealth and relevant State Parliaments in 1915. (Whilst the reaching of this interstate agreement may appear to have taken an inordinate time, it anticipates by nearly twenty years the setting up of the famed Tennessee Valley Authority in the United States of America.)

The Act provides for a River Murray Commission of four members, comprised of a Commonwealth representative as President, and one from each of the three States. The Commission is not a constructing authority, each State being responsible for the design, construction, maintenance and operation of the relevant works under its control, subject to the general approval and direction of the Commission. The capital cost of the works is now borne in equal shares by the three States and the Commonwealth, but initially the latter's contribution was to have been limited to £1,000,000. However, the cost of operation and maintenance is shared by the States only.

[10] *Ibid.*

The Agreement, which is a schedule of the Act, provided for a storage on the Upper Murray, a storage at Lake Victoria, twenty-six weirs and locks on the Murray from Blanche Town in South Australia to Echuca in Victoria, and nine weirs and locks on the Murrumbidgee from its junction with the Murray to Hay, or alternatively on the Darling, from its junction with the Murray. With this assemblage, the Commission would then be able to apportion the Murray waters between the States and also meet South Australia's insistence on provision for navigation.

Although still the same in principle, there have been subsequent amendments to the Agreement, and not all of the original proposals have been implemented. However, works under the modified Agreement allow adequate administration of the scheme and afford additional advantages, e.g., barrages at the mouth of the Murray.

The regulating storage on the Upper Murray is provided by the Hume Reservoir, which has been constructed in three stages. The first was completed in 1936, and the last, which doubled the original storage capacity to 2,500,000 acre-feet, in 1961. (A hydro-electric station, with two 25 MW generators, was incorporated in 1957, the electricity to be shared by Victoria and New South Wales.) Lake Victoria, in New South Wales, near the South Australian border, is a natural lake off the river, and works completed in 1928 allow it to be operated as an intermediate regulating storage. However, at this writing, preliminary work on construction of Chowilla Dam has commenced, and, when completed to its presently designed capacity, it will provide a storage of some five million acre feet, and will encompass Lake Victoria. It then will be the largest storage in Australia. The site is about six miles downstream of the Victoria-South Australia border, and although the dam is to be only 48 feet high, the gradient of the river is so low that water will be backed as far upstream as Wentworth, some 120 river miles, and 550 square miles of river flats will be inundated (River Murray Commission, 1965).

With the completion of Chowilla Dam, South Australia's water requirements, as presently envisaged, will be assured. There are, however, many problems in locating, constructing and operating a major storage in such an area, and some of these are still under investigation. A lock will be incorporated in the structure to allow navigation.

Of the weirs and locks proposed in the original Agreement, thirteen have been constructed, all between 1922 and 1935. The first completed, at Blanche Town, South Australia, is also the closest to the mouth, 171 miles, and they extend to Torrumbarry, 1,020 miles from the mouth. The weirs and locks serve both to aid navigation and to facilitate removal of water for irrigation. The original insistence on navigational facilities by South Australia was, of course, based on cargo transport, but to-day the main navigational usage is by small craft, and there is virtually no cargo movement through them.

In addition to the weirs and locks, three weirs have been constructed. Yarrawonga Weir, on the Murray, is the largest of the Commission's weirs and the furthest upstream, being only 145 miles from Hume Reservoir. It was completed in 1939 and allows diversion of river water into two large canals, Mulwala in New South Wales, and Yarrawonga in Victoria, to serve irrigation areas in the respective States. The other two weirs, both completed in 1940, were constructed for flood diversion purposes on the Murrumbidgee at Redbank and Maude.

The Commission has not had any works constructed on the Darling River, but on completion of the Menindee Lakes storage scheme by the W.C. & I.C. in 1960, the Menindee Lakes Agreement between the four Governments gave the River Murray Commission direct control of a considerable part of the available water for a period of seven years as from January, 1963. This period was based on the anticipation of Chowilla storage operating by the end of 1969. The Menindee Lakes storage is the first major water conservation work on the Darling River. It utilizes three natural lakes adjacent to the Darling, with their holding capacity increased by embankments, together with a weir on the Darling to form a fourth lake. Water can be released either into the Darling or its great Anabranch.

The barrages constructed at the mouth of the Murray are an important addition to the original Agreement. The five barrages, completed in 1940, have an aggregate length of five miles, and serve to prevent ingress of the sea in periods of low flow, as well as permitting watering by gravitation of a number of areas of reclaimed river flats.

The Murray River Valley now has the greatest development of irrigation areas in Australia, and the fact that they are spread over three States, harmoniously served from the same water source, is a tribute to the co-operation that has been finally achieved between the States. A little reflection will indicate the enormous complexity of effectively administering water delivery to these irrigation areas. They are distributed along a river length of well over 1,000 miles, and it may take a month or more for water released from the headwater storage to reach some of the downstream areas. The control of flows in the system involves a network of gauging stations, the effective use of downstream regulating storages, information on the day-to-day requirements of the areas, allowance for seasonal conditions, and not a little inspiration.

At present there is far more irrigable land and irrigation demand, both in the Murray and the Murrumbidgee, than there are water resources. However, on completion of the Snowy Mountains Scheme (q.v.) additional water will be available for use by New South Wales in the Murrumbidgee (via Blowering Dam, now under construction), and for joint State use in the Murray. In the latter case, the average annual increment will be over 800,000 acre-feet, entering the Murray system via Swampy Plain River, near Khancoban.

### Problems in the Great Artesian Basin

While the major surface water projects of the Murrumbidgee and Murray Valleys were being instigated, development was proceeding rapidly in the Great Artesian Basin, and this, too, brought its problems. With bores tapping aquifers at depths of 1,000 to 4,000 feet, construction and completion techniques were generally inadequate for proper control of the high-pressure water. It was found, too, that the flows although initially often large (flows in excess of two million gallons per day were not uncommon) soon showed a marked fall-off. Various theories were advocated to explain this, e.g., leakage into upper formations, caving of the aquifer, choking of the bore, loss of gas pressure, and regional loss of hydraulic head, due to droughts, but none was sufficient to be of general application. In some areas, too, difficulties were being experienced because of severe corrosion, steel casing in the bores being sometimes eaten through in a matter of months. Furthermore, with regard to the potential of the Basin's water resources, and their appropriate development, many conflicting views were raised. Even opinions as to the source of the water were by no means unanimous, a matter which raised an interesting controversy.

Well before 1900, the origin of water in artesian basins, or, for that matter, virtually all underground water, was recognized as being of meteoric origin, i.e., from rainfall. However, J. W. Gregory, Professor of Geology at Melbourne University (and later, Glasgow University), caused something of a scientific stir by advocating a plutonic origin, i.e., from deep-seated igneous rocks. His views were first aired at a lecture in 1901, and were refuted by Knibbs.[11] Gregory developed his theories further in his book "The Dead Heart of Australia" (1906),[12] basing his case mainly on the anomalies in

[11] Knibbs, G. H., 1903, "The Hydraulic Aspects of the Artesian Problem", *Jour. Roy. Soc. New South Wales,* XXXVII, p. xxiv-xliv.

[12] Gregory, J. W., 1906, "The Dead Heart of Australia", John Murray, London; 1911, "The Flowing Wells of Central Australia", *Geog. Jour.,* XXXVIII, No. 1 (July), p. 26-59, No. 2 (Aug.), p. 157-181.

temperature and pressure, the chemical composition of the water, and erroneous hydraulics, and claimed that the rise of the artesian water was due to the combined effects of the temperature of the igneous rocks from whence the waters emanated and the pressure of the overlying rocks. New South Wales Government Geologist Pittman, who had been active in the study of the Artesian Basin for many years, attacked Gregory's theories in his Clarke Memorial Lecture to the Royal Society of New South Wales in 1907.[13] However, not to be outdone, Gregory criticized Pittman's arguments and maintained his views. The final broadside by Pittman replied in considerable detail (and includes a 15-page bibliography), but Gregory remained unconvinced.

Nevertheless, even apart from the controversy as to the origin of the water, the marked reductions and cessations of flows caused considerable alarm, particularly amongst pastoralists, it being feared that this valuable resource may have a relatively short life. It was evident that the whole matter required careful investigation and review, and to this end, in 1908, the Government of New South Wales invited other States to form a consultative Board. Unfortunately, only South Australia was willing, and the matter lapsed. It was revived again in 1911, this time successfully, and the First Interstate Conference on Artesian Water was held in Sydney in 1912.

The report of the first conference gives a valuable review of the state of knowledge of the Great Artesian Basin at that time. Its contributions included a geological map of intake areas, and maps showing isopotential contours, temperature, and reduced levels of the main flows in the New South Wales section of the Basin. The conference gave special attention to the question of the source of the water and the cause of the flows, and discounted the plutonic theory. Many other matters and problems were aired, and it was evident that much remained to be done. The resolutions of the conference called for further work on such matters as delimiting the boundaries of artesian basins in Australia, hydrographic surveys to ascertain the losses from drainage systems traversing intake areas, recording annual withdrawals of water from bores, collecting and classifying rocks encountered in boring, adopting uniform bore-casing, analysing artesian waters, investigating reasons for the decrease in flows and means of prevention, and overcoming corrosion of bore casing. It also called for

[13] Pittman, E. R., 1907, "Problems of the Artesian Water Supply of Australia with special reference to Professor Gregory's Theory", Government Printer, Sydney); 1908, *Jour. Roy. Soc. New South Wales,* XLI, p. 100-139 (Clarke Mem. Lecture); 1914, "The Great Artesian Basin and the Source of its Water", Government Printer, Sydney.

uniform legislation to control the development and utilization of artesian waters, and proposed that there be a permanent interstate board of investigation, to meet annually.

At the second interstate conference in Brisbane (1914) progress reports were made by each State. Systematic gaugings of pressure and flow had been instituted, and it was evident that the flows were still falling off. Observations on bores carefully constructed and completed showed that the diminution of flow was due to reduction of pressure and not to other factors such as caving of the formations or leakage. (A reasonably complete understanding of the behaviour of the artesian bores had to wait the development of the theory of elasticity of aquifers, and more importantly, the derivation of the non-equilibrium equation by Theis in 1935.)

Owing to the intervention of World War I, the next conference was not held until 1921, at Adelaide. Considerable data had been accumulated from systematic measurements of pressure, flow and temperature, and, in its progress report, New South Wales presented potentiometric contours which clearly indicated from the hydraulic gradients that water in the eastern lobe of the New South Wales section of the Basin was derived from intake areas within New South Wales, whilst waters west of Mungindi were from Queensland sources. Data on thermal gradients were also presented, and it was pronounced that the variations in gradient were due to variations in thermal properties of the rocks and did not indicate a plutonic source. This has been borne out in subsequent studies. Thermal gradients in the New South Wales section of the Basin range from 1·25 to over 4·0 degrees Fahrenheit per 100 feet and show a close relationship to the nature and thermal conductivity of the basement rocks.[14]

At the Fourth Conference in 1924, at Perth, the need to extend the activities of the conference to cover not only artesian water, but all underground water, was an agenda item. However, no resolution was made in this regard. The matter was revived at the Fifth Conference in 1928, at Sydney, and it was resolved that "the whole body of underground water, whether under pressure or not" should come within the scope of the conference. Unfortunately, although it was proposed that the next meeting be in 1930, this proved to be the last of this series of Conferences on Artesian Water. Even so, they had been of enormous benefit. They clarified many problems, allayed many fears, instigated the systematic collection and interpretation of data on Australian artesian basins, and stressed the need for controlled development of artesian water resources.

[14] Hind, M. C., 1963, "The Geology of the N.S.W. Portion of the Great Artesian Basin", Unpub. Rep., W.C. & I.C., Sydney.

The period covered by the conference was one in which very rapid progress was made in the knowledge and development of New South Wales' resources of groundwater (used here in the modern sense of all underground water, confined or unconfined). The New South Wales Geological Survey mapped the geology and collected data on bores and wells in large areas in central and western parts of the State, particular attention being paid to areas marginal to the Artesian Basin because of the need to establish its limits and to delineate intake formations. The information obtained and collated was invaluable in determining the stratigraphic sequence in the intake areas, as well as establishing general geology-groundwater relationships of large areas marginal to, but not part of the Artesian Basin.

In this period, too, close liaison was maintained between the New South Wales Geological Survey and the Boring Branch of the W.C. & I.C., the latter branch having been taken over from the Public Works Department by the Commission when it commenced operations in 1913. Because of the geological control on groundwater occurrence, the geologists were needed to advise on the prospects of obtaining water by boring in the various areas, as well as examining and collating information on strata penetrated and, in the case of the Basin, determining when basement rocks (bedrock) had been encountered. The Water Act (1912) required that bores and wells be licensed, so that the information on strata penetrated, depth, quality and yield of water, and other relevant details, could be obtained and incorporated in the W.C. & I.C. records of groundwater resources of the State. Thus, in conjunction with the geology, a very valuable body of data was gradually accumulated. Unfortunately, this important legislation required that a licence be obtained only if a bore or well were over 100 feet in depth, and west of a line from Albury, through Tamworth, Bingara and Inverell, to Bonshaw, so that much significant information has been lost, particularly in the eastern half of the State. This situation was not remedied until 1955, when an amendment to the Act made all bores and wells in the State, irrespective of depth and location, subject to licence. The licence is free, except in the case of an artesian bore, where the charge is $10. (Some States are still without legislation of this nature, an omission which has severely handicapped assessment of their groundwater resources because of lack of recorded data.) In a 1966 amendment, all sub-surface water was vested in the Crown, with the W.C. & I.C. the controlling authority. This finally put groundwater on a similar footing to surface water, which had been vested in the Crown by the Water Rights Act of 1896-1902, and for which a licence is required to authorize pumping from rivers and lakes (other than for stock and domestic purposes) or to construct dams or weirs on watercourses.

Although there were no further Artesian Water Conferences, this is not to say that all problems were solved. In fact, the various States continued with relevant studies. However, at a Brisbane meeting of the Australian Agricultural Council in 1937, the national aspects of water conservation and irrigation schemes and problems were stressed and a joint Commonwealth and State enquiry was recommended. An Interstate Conference on Water Conservation and Irrigation was subsequently convened in Sydney in 1939, but the Commonwealth was not represented. The matters considered by this conference were of very wide scope but the first resolution in its report recommended that the States and the Commonwealth participate in "a national investigation into the question of underground water supplies and the matters relating thereto".

With regard to artesian water, the W.C. & I.C. had been engaged in a study of the behaviour of the New South Wales section of the Basin, and the problems of its development and use, and an interim report of the findings was presented at the conference. (A further interim report on this study was compiled the following year.)

The conference also resolved that "a permanent advisory committee or council, consisting of representatives from each State and from the Commonwealth, should be formed to consider and advise on those problems relating to the conservation and utilization of water, which are of national or interstate interest and importance". It recommended that this matter be referred to a proposed further conference "for recommendations as to the constitution, powers and duties of such committee or council". Unfortunately, World War II burst onto the scene, and it was to be many years before these proposals came to fruition.

## Post-World War II Developments

With the end of World War II in 1945, water developments in New South Wales entered a period of ever-increasing activity. Initially, this was due not only to the resurgence to be expected when a nation can return to normal pursuits, but also, no doubt, to the fact that New South Wales was experiencing a long period of severe droughts. (Commencing in 1935, a succession of droughts occurred, with maximum intensities inland in 1938, 1940 and 1944, and continuing until 1947.)[15]

[15] Foley, J. C., 1957, "Drought in Australia, Review of Records from Earliest Years of Settlement to 1955", Bull. 43, Commonwealth Bureau of Meteorology, Melbourne.

One of the first significant post-war developments, serving to help re-establishment, and, as an anti-drought measure, to encourage landholders to make provision for adequate water supplies on their properties, was the introduction of the Farm Water Supplies Act in 1946. Under this Act, primary producers can obtain technical advice on water supply schemes on their properties. Such schemes may involve construction of dams, excavated tanks, bores, wells, or the use of creeks, rivers and lakes, to provide water for irrigation, stock or domestic purposes. For approved schemes, financial assistance up to 90% of the cost of the works is available at low interest rates, with repayments over a period of up to 15 years. This Act has proved to be of great benefit to landholders, helping to stabilize or increase their productivity, and providing for some measure of protection from drought. The W.C. & I.C. administers the Act, and, for the technical advisory service, maintains a staff of engineers for surface water projects, and hydrogeologists for groundwater projects. Up until 1966, over 22,000 requests for technical assistance had been dealt with. The majority did not require financial assistance, but advances of some $5,700,000 had been made in respect of 2,275 applications (W.C. & I.C. Annual Report, 1966).

## Research Developments

Exciting possibilities were opened up when, on February 5, 1947, over the Blue Mountains area, west of Sydney, C.S.I.R.O. cloud-seeding experiments induced the first man-made rain. (This followed on American experiments which had caused snow to fall over Pittsburg the previous year (Current Affairs Bulletin, 1957).) The thought of being able to cause rain to fall over a dam catchment or a drought-stricken crop area captured public imagination, and great interest was shown in the investigations undertaken by the C.S.I.R.O. Radiophysics Laboratory from Sydney. These investigations made Australia the leader of the field of "rain-making", but the results are still somewhat controversial. Smith[16] (1964) reviews the outcome of large-area experiments over the Snowy Mountains, New England and Warragamba catchments in New South Wales, the Mt. Lofty Ranges in South Australia and the Darling Downs in Queensland, some of which gave indications of increased rainfall, while others showed no significant effect, or even lower rainfall. There are indications that the apparently conflicting results are due to the different types of air masses, with clouds forming in continental air masses, as over the Snowy Mountains or New England, being more favourable than those from maritime

[16] Smith, E. J., 1964, "Possibilities of Artificial Modification of Precipitation", Paper B2 in "Water Resources Use and Management", University Press, Melbourne.

or tropical situations. Investigations are continuing, but it is clear that the panacea for our drought-prone country has not yet been found.

"Rainmaking" is, of course, but one of the many water research projects undertaken by C.S.I.R.O., as will be seen by glancing through its Water Research Bibliography.[17] Much of this work has been carried out in other States, and is often essentially of local application. However, some of the projects have broad application and significance irrespective of where the basic research is undertaken. One of these that has created particular interest is evaporation control, with its obvious application to retardation of evaporation from surface storages in arid areas. Research on the use of mono-molecular layers spread over the water-surface to retard evaporation was commenced by C.S.I.R.O. in 1952, and successful results were reported in 1955.[18] The compounds best meeting the requirements, i.e., cheap, non-toxic, and capable of rapid spreading, were found to be cetyl alcohol (hexadecanol) and stearyl alcohol (octodecanol) and reductions of 15 to 70 per cent of evaporation were obtained on small storages, depending on dosage and climatic conditions. However, in some cases the method failed, the main reason being attributed to the occurrence of an unfavourable natural surface film. Other difficulties arose when the process was applied to large storages, winds being found particularly troublesome. Experiments on the Stephens Creek and Umberumberka Reservoirs at Broken Hill, New South Wales, are reported to have reduced evaporation by 37% and 17% respectively, and treatment costs here and at Mary Kathleen, in Queensland, ranged from 1c to 5c per 1,000 gallons saved. There are still many problems to be overcome in the field of evaporation control, and although results have not been as favourable as was first hoped, research in progress may well provide the answers.

A fine example of how one piece of research can lead to another is given by the fact that the experiments on evaporation suppression encouraged work along similar lines on plant-transpiration suppression. Initial results by C.S.I.R.O. have shown that with some treatments the reduction in transpiration of plants can be greater than that of the corresponding reduction in photosynthesis.[19] In other words, there is scope for improving water-use efficiency in plants. Experiments have mainly aimed at applying substances which will either cause a low permeability film on the leaves, or induce partial stomatal closure, and

[17] Davey, L., 1964, "C.S.I.R.O. Water Research Bibliography, 1923-1963", C.S.I.R.O.; also supplement—"Selected Supplementary Entries, 1963-1967".

[18] Mansfield, W. W., 1964, "Control of Evaporation", Paper B5, in "Water Resources Use and Management", University Press, Melbourne.

[19] Slatyer, R. O., and Denmead, O. T., 1964, "Water Movement through the Soil-Plant-Atmosphere System", Paper C2 in "Water Resources Use and Management", University Press, Melbourne.

it is interesting that one of the compounds showing promise is cetyl alcohol. These investigations are still in relatively early stages, but it needs little imagination to realize the importance of a successful outcome.

A further research field of world importance, and one in which there is considerable public misconception, is that of desalination of water. This matter has been of long interest to man, but in terms of research, the main impetus has been since World War II. Very active research programmes are in hand by many organizations around the world, the main processes under investigation being distillation, freezing, solvent extraction, hydrate processes, reversed osmosis, electrodialysis and ion exchange, and a fair degree of success has been achieved. C.S.I.R.O. entered this field in 1955 in Melbourne and has concentrated largely on distillation processes.

In a valuable review of desalination processes, an Advisory Panel on Desalination (1966) concluded that in Australia only the methods based on distillation or electrodialysis can be considered for immediate application, and then only under such conditions that the nearest available sources of natural supply were so distant that pipe-line costs were likely to be excessive (for large communities, the latter distance could be several hundred miles). The Australian Water Research Foundation (q.v.) has also concerned itself with reviewing desalination processes and their economics.

## The Dumaresq-Barwon Border River Commission

The question of joint control and use of border rivers had been the first agenda item for the 1939 Interstate Conference, and it had been resolved that an enquiry should be set up by representatives of the States concerned. The Murray River Commission had long since been in operation for that river, but the only other border river system, the Dumaresq-Barwon, was still subject to independent control by the States concerned. Consequently, there were anomalies, e.g., in New South Wales, an irrigator pumping from the Dumaresq River had to pay a Water Rights fee, but in Queensland, across the river, no fee was required. There were also proposals to construct a series of weirs on the Dumaresq and Barwon Rivers, and a headwater storage on the Dumaresq, and it was clear that an interstate agreement was essential. Action in this regard was finalized soon after the War, when the New South Wales-Queensland Border River Agreement was entered into by the Premiers of the two States in August, 1946. The Agreement was ratified by the respective State Parliaments and the Acts came into force on July 1, 1947. The Dumaresq-Barwon Border Rivers Commission was then set up and held its inaugural meeting in Sydney in

September, 1948. (The Commission consists of a Chairman and two Commissioners, one representing Queensland and the other New South Wales.)

In accordance with the Agreement, the Queensland Irrigation and Water Supply Commission is the constructing authority for weirs and regulators on the border rivers and the New South Wales W.C. & I.C. is the constructing authority for a headwater storage dam. The existing weir on the Barwon River, at Mungindi, was formally handed over to the Border Rivers Commission in November, 1948, and in June, 1949, a ceremony was held to drive the first pile in Bonshaw Weir, the first of the works to be undertaken under the Agreement. With subsequent works there are now six weirs, but, as yet, no headwater storage, and the Commission considers that construction of further weirs along the Border Rivers as pumping storages is not justified until such time as a head storage is constructed (Dumaresq-Barwon Border Rivers Commission Annual Report, 1965). Considerable investigation had previously been devoted to a dam site at Mingoola, on the Dumaresq, but the site was found to be unsatisfactory. Investigations were then directed to a dam site on the tributary Pike's Creek (Queensland) and these were nearing completion in 1966.

An investigation has also been made as to the possibility of irrigation development from groundwater resources of the alluvium of the Dumaresq valley. This was commenced in 1958 by the Queensland Irrigation and Water Supply Commission, in liaison with the New South Wales W.C. & I.C. with costs shared. However, the groundwater potential was found to be relatively limited, sufficient for only small-scale individual property projects, and the water quality unfavourable for the growing of tobacco, the main crop for which water supplies were sought.

## Further Expansion of Sydney's Water Supply

The series of droughts commencing in the mid-thirties, and continuing through the War, also made it evident that Sydney's water supply had again been outgrown, and led to the construction of the world's largest dam for metropolitan water supply, Warragamba. Faced with serving an area extending over 4,000 square miles (compared with 460 square miles for Los Angeles, the largest city area in the United States) and with an ever-increasing expansion of population and industry, the Sydney Water Board had always had the problem of keeping pace with demands. Development of the Upper Nepean catchment had long been the mainstay of Sydney's water requirements, commencing with a ten-foot dam at Pheasant's Nest, from which water was diverted to Prospect Reservoir and thence to Sydney, the scheme which had been rushed to a finish in 1886. The extreme droughts at the turn of the century created a further emergency and, to safeguard against a recurrence of drastic water shortage, work was commenced in 1903 on Cataract Dam as one of a series of major dams on the Upper Nepean tributaries. With the completion of Cataract Dam in 1907, Cordeaux in 1926 (wet years and World War I delayed construction), Avon in 1928, and Nepean in 1935, the Upper Nepean catchments had been developed almost to their limit. To supplement them, a dam on the Woronora River was completed in 1941, after long delays due to the Depression years. But even before then, the Board was aware that still greater storage facilities were essential, and attention was directed to the vast catchment of the Warragamba River, a source which had been suggested as early as 1845.

Development of the Warragamba commenced with the construction of a 50-foot weir, completed in 1940, from which water was delivered from an underground pumping station to Prospect Reservoir. However, in 1946, with the War over, intensive investigations were begun with the object of commencing a major dam as soon as possible. Although outwardly the long Warragamba gorge offered ample scope for dam sites, test drilling and detailed geological examination revealed various undesirable features and a site was finally fixed to avoid most of these.[20] Preliminary construction commenced in 1948, and the giant monolith, the highest concrete dam in the Southern Hemisphere, was completed in 1960. At top water level, Warragamba Dam holds some 452,500 million gallons, more than three and a half times the combined capacity of all of the other dams in the Sydney water supply system, and, in terms of storage, Sydney should not have any worries for many years hence. Even so, aware of the likely future growth and development within the area served by the Board, preliminary investigations of further storage facilities, both in the present catchments and in others such as the Shoalhaven and Grose Rivers, are in progress.

## The Broken Hill Water Board

With the end of the War, and having been beset by droughts, the Broken Hill Water Board took steps to provide a more reliable water supply. Being in an area of high evaporation and low and very variable rainfall, water supply had always been a particular problem for Broken Hill, and on a number of occasions the city had had to depend on water being brought by train. It was evident that schemes based on local sources of water could not meet requirements, so, in 1949, work was commenced on a pipeline scheme, involving two pumping stations

[20] Brown, W. R., Waterhouse, L. L., Moye, D. G., 1957, "Preliminary Geological Investigation in Connection with the Proposed Warragamba Dam", *Jour. Inst. Eng. Aust.*, V. 23, p. 74.

and 62 miles of 24-inch diameter, concrete-lined, steel piping, to bring water from the Darling River. With the completion of this scheme in 1952, Broken Hill at last had an assured water supply, and this was further safe-guarded by the completion of the Menindee Lakes scheme by the W.C. & I.C. in 1960.

Apart from the Sydney and Hunter District Water Boards, the Broken Hill Water Board is the only other statutory water supply authority in the State, the Public Works Department being the responsible authority for other town water supplies. However, Broken Hill's first water supply scheme was actually undertaken and operated by a private company (The Broken Hill Water Supply Company Limited) which constructed the Stephens Creek Dam some 11 miles north-east of the town in 1892. When this became inadequate, a dam was constructed on Umberumberka Creek in 1915, at a site about 24 miles north-west of Broken Hill, and the following year the Public Works Department took over as the water supply authority. Finally, the Broken Hill Water Board was established in December, 1938, taking over administration in January, 1939. Its responsibilities extend from Menindee on the Darling River to Radium Hill in South Australia, involving 144 miles of pipeline.

## The Snowy Mountains Scheme

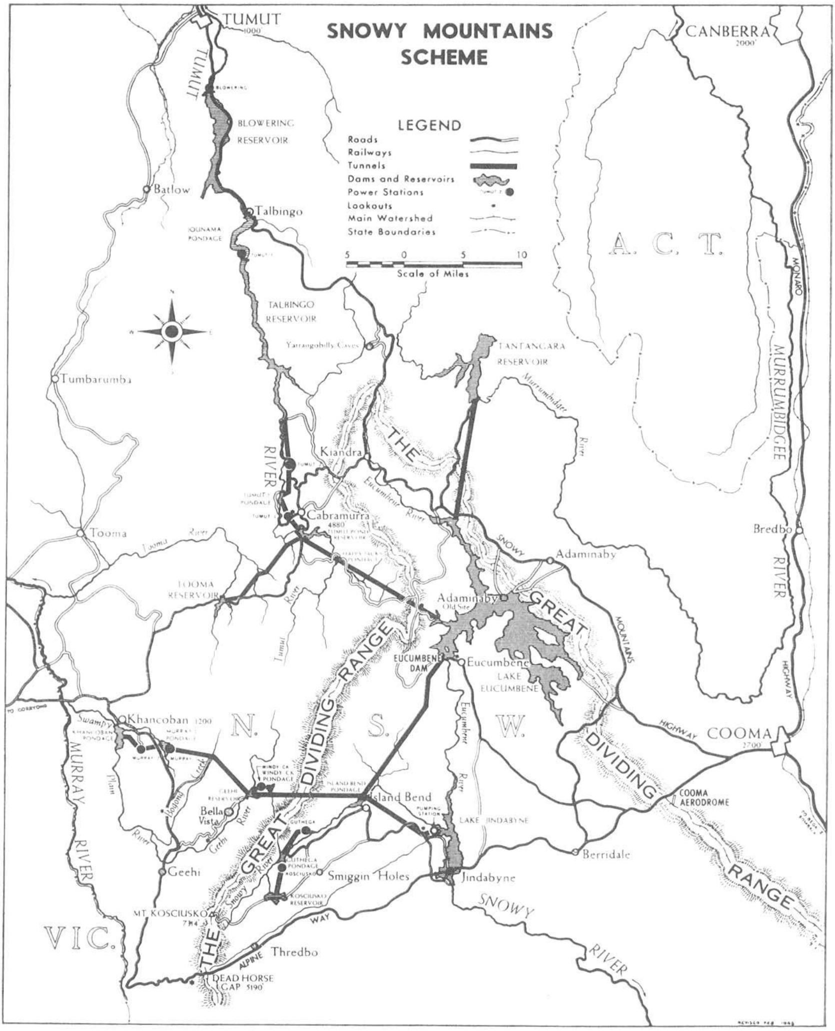
Of all post-war developments in Australia, the Snowy Mountains Scheme is by far the most outstanding. It is one of the largest civil engineering works under construction in the world, and its features and magnitude have attracted world attention.

In principle, it is by no means a new scheme. Early in the 1884 Royal Commission on Conservation of Water, Surveyor-General Adams stated he believed a large supply of water could be diverted (by surface aqueducts) from the Snowy River to supplement the discharge of the Murrumbidgee, and a surveyor was deputed to take the necessary levels. Home (1897)[21] considered the proposal and concluded it to be too costly and unremunerative. He stated "the idea of utilizing the water of the Snowy River outside of its own valley must therefore be abandoned". However, the idea persisted, and many variations were put forward over the years.

In 1913, at the Conference of Interstate Engineers on the River Murray, J. S. Gregory proposed diversion of the Snowy to the Murray by means of tunnels, and in 1918 proposals for developing hydro-electric power from the Snowy were investigated. One scheme even proposed the use of Snowy waters for Sydney water supply! But in spite of the many schemes and investigations, nothing was achieved.

[21] *Ibid.*

The severe drought situation in the late thirties renewed pressure from a number of factions to implement schemes for the Snowy waters to serve their particular interests. Consequently, to investigate the




Area map of the Snowy Mountains Scheme.
(Courtesy Snowy Mountains H.-E.A.).

whole question of using Snowy waters, the New South Wales Government set up the Snowy River Investigation Committee in 1942, and in its report in 1944, the committee recommended the diversion of the Snowy to the Murrumbidgee for a combined irrigation-hydro-electric scheme.

The latter proposal aroused violent opposition from Victoria and Murray River interests, and the Commonwealth was asked to intervene. Eventually, at a Ministers' Conference in June, 1946, the Commonwealth and the two States agreed to investigate the matter from a national viewpoint, it being clear by this time that for post-war reconstruction and national development there was urgent need for increasing both power production and food supplies. A technical committee was set up that year, and in its first report in 1948 recommended immediate adoption of a plan to divert the waters of the Eucumbene, Tooma and Upper Murrumbidgee Rivers to the Tumut River, a tributary of the Murrumbidgee. In a later report, the committee also recommended diversion of the Snowy, downstream of its confluence with the Eucumbene, to the Murray River. These plans not only allowed for the waters of the Snowy and Eucumbene Rivers to be available for irrigation development in the Murray and Murrumbidgee Rivers, but also for the production of power from the fall of the diverted waters of some 2,700 feet, a power potential some ten times as large as that given by any previous proposal.

The technical committee's recommendations were accepted at conferences of Commonwealth and State Ministers and Officers in 1949, and to implement them the Snowy Mountains Hydro-Electric Power Act was passed by the Commonwealth Government in July, 1949. The Snowy Mountains Hydro-Electric Authority, a statutory body constituted under the Act, came into being on August 1, 1949, with Mr. (now Sir) William Hudson the first Commissioner, and an immediate start was made with planning, detailed investigation and design.

Broadly, the Snowy Scheme provides for a complex of 17 large dams and many smaller ones, nearly 100 miles of tunnels, nine power stations, over 80 miles of high mountain aqueducts, some 400 miles of power transmission lines, a network of roads, and two new townships. It was evident that the complexity and magnitude of the Scheme would require the integration of engineering and scientific disciplines on a scale hitherto unprecedented in Australia, and, to this end, the Engineering Laboratories of the Authority were set up in 1951. Their work may be divided into five main functions, viz., engineering geology, construction materials, physical sciences, fluid mechanics and technical and general services. With facilities unrivalled in Australia, and a staff of over 130 scientists and assistants, the Laboratories have contributed in no small measure to the speed and success with which the Scheme has progressed.

The Scheme consists of two major segments termed the Snowy-Tumut Development and the Snowy-Murray Development. Common to both is the main regulating storage of Eucumbene Dam, which was completed in 1958. Its storage capacity of 3·9 million acre-feet makes it the largest yet constructed in Australia.

The Snowy-Tumut Development will be served by storages on the Eucumbene, Upper Murrumbidgee and Tooma Rivers, and a system of diversion tunnels to bring the waters of these rivers into the Tumut Pond Reservoir, near Cabramurra, on the Tumut River. From this reservoir, the combined flow from the four rivers will pass in succession through three power-generating projects spaced along the Tumut Gorge (two of these projects, Tumut 1, 1,200 feet underground, and Tumut 2, 800 feet underground, are completed), to finally reach the Blowering Reservoir. This will hold the waters discharged from the power projects during the winter months and release them through a further power station during summer as required for irrigation in the Murrumbidgee Valley. The fall from Tumut Ponds Reservoir and the outlet of Blowering Power Station is some 2,700 feet, and the four power stations will have a total generating capacity of over two million kilowatts.

Blowering Dam is under construction at this writing, and is scheduled for completion in 1968. Its completion will allow full development of the 500,000-acre Colleambally Irrigation Area (q.v.), some 250 miles downstream, which is currently being partially settled. It is estimated that the Snowy-Tumut Development, on completion, will provide an additional regulated water supply of some 1,100,000 acre-feet per year to the Murrumbidgee river. This water will allow new extension of the Colleambally Irrigation Area, and permit further development on lands west of the Murrumbidgee Irrigation Area and along the lower Murrumbidgee.

The Snowy-Murray Development involves the diversion of the Snowy River through a trans-mountain tunnel system to the western side of the mountains. Travelling through tunnels, shafts and pipelines, the diverted waters will fall some 2,600 feet. The two major power stations, Murray 1 and Murray 2 will have an aggregate generating capacity of about one and a half million kilowatts, and additional power will also be generated by three smaller stations utilizing the waters being diverted from the higher streams and rivers before they reach the main trans-mountain tunnel system. The water will finally be discharged into the Swampy Plain River from the regulating storage of Khancoban Dam, and thence into the Murray River. On its completion, scheduled for 1969 (the Snowy Mountains Authority has been notable for having its various works completed on or before schedule), the Snowy-Murray Development is estimated to provide an additional regulated flow of 800,000 acre-feet per year into the Murray, and this will allow the expansion of existing irrigation areas in New South Wales and Victoria.

The accompanying map shows the main features of the Snowy Scheme, but it is difficult to convey from a map or a few words its scope and magnitude. Perhaps some indication can be given by the fact that the American Society of Civil Engineers, in consultation with national Engineering Societies of other countries, lists it as one of the "Seven Future Engineering Wonders of the World".

## River Improvement Works

A problem tackled soon after World War II was that of improving the effectiveness of streams and rivers. In many cases, channel capacities had been seriously reduced over the years by the build-up of obstructions such as fallen or growing timber, and the accumulation of sands and gravels due to bank and other erosion, particularly after drought periods and in areas of excessive land-clearing or over-stocking. It was evident that provision for systematic remedial measures was required, and, to set up the necessary organization, the Rivers and Foreshores Improvement Act was passed in 1948. Works downstream of tidal influence are under the jurisdiction of the Department of Public Works, and those upstream of tidal influence, and on inland streams, are the responsibility of the W.C. & I.C. The works covered by the provisions of the Act are not confined only to clearing stream channels but also include changing, or preventing from changing, the course of streams, stabilization and protection of stream banks, the construction of levees to assist in preventing flooding, the provision of flood gates and drainage schemes, and dredging of waterways.

Works may be carried out directly by the W.C. & I.C. or the Department of Public Works, whichever is appropriate, or by Local Government authorities under agreement, with technical advice, supervision and financial assistance from the Commission or Department. Alternatives are for the works to be undertaken in association with another State or Federal authority, or by another State authority under advice.

Shattock (1966)[22] outlines the main works undertaken on non-tidal streams. Local county or shire councils have carried out such works as stream clearing or flood protection levees in the Belubula, Bell, Macquarie, Murrumbidgee and Macleay Rivers, with the W.C. & I.C. contributing from 50% to 66% of the cost. The Commission itself has carried out clearing, realignment and bank protection works on the Tumut River, from Blowering dam-site to

[22] Shattock, W. H., 1966, "A Review of River Improvement Works on Non-Tidal Streams in New South Wales", *Jour. Inst. Eng. Aust.*, V. 39, p. 275-282.

the Murrumbidgee, and on the Swampy Plain and Upper Murray Rivers. These streams are involved in the Snowy Mountains Scheme and costs have been shared with the Snowy Mountains Authority, and in the latter case, also with the Victorian State Rivers and Water Supply Commission.

The Hunter Valley (q.v.) is a particular case, having its own Conservation Trust. Extensive improvement works, including realignment of the Hunter River at Denman and Singleton, have been undertaken by the W.C. & I.C. on streams within the Hunter catchment, particularly since the passing of the Hunter Valley Flood Mitigation Act in 1956. Following the latter Act, too, the Department of Public Works commenced an extensive flood mitigation programme in the lower river area. Prior to July, 1963, costs were shared on the basis of 25% from the Conservation Trust and 75% from the W.C. & I.C. or, for works in tidal sections, the Department of Public Works. Since then, the Trust contributes one-seventh of the costs and the Commonwealth and State share the remainder.

The Macleay River County Council, which added river improvement and flood mitigation works to its responsibilities in 1954, is also actively engaged on a planned programme of such works in both tidal and non-tidal sections of the Macleay River. Since 1963, this Council has also received Commonwealth financial assistance, as have county or shire councils for the Tweed, Richmond, Clarence and Shoalhaven Rivers for a six-year programme of flood mitigation works in tidal sections.

## The Hunter Valley

The Hunter Valley can well be considered separately because in it the concept of the river basin unit has been strongly developed since World War II. It is one of the largest of the coastal river basins, and, with its primary and secondary industries, plays an important role in the economy of the State. The primary industries dependent on water supply have always been drastically affected by the extremes of drought and flood, but the situation with regard to the latter is further aggravated in the Hunter Valley because a number of the towns are unfortunately sited on the flood plains of the river. Regulating storages and flood mitigation works had long been advocated, but, apart from levees in the lower river area, little had been achieved prior to World War II. At this stage, the only major storage within the catchment was Chichester Dam, completed in 1924, but this was for Newcastle water supply.

In 1939, a site was selected for Glenbawn Dam, on the upper Hunter River, but war intervened and enabling legislation for its construction was not passed until 1946. It was initially proposed that the dam be an irrigation water supply storage only, with a capacity of 119,000 acre-feet. However, in the early stages of construction, because of the need for additional storage and the demand for flood mitigation measures, the design was amended to allow for a total capacity of 293,000 acre-feet, of which 108,000 acre-feet would be operated for flood mitigation and the remainder for irrigation and other requirements. Construction was rather protracted, particularly during 1947-1954, when national post-war reconstruction activities caused intense competition for man-power, plant and materials. The dam wall was finally completed in 1957, and, with the closure of the diversion tunnel in May, 1958, commenced storing water. This is the first major water conservation storage constructed on a coastal stream in New South Wales, but it regulates only 9% of the annual yield of the Hunter basin.

Long before the war, it had been proposed that the dam should serve a 28,000-acre irrigation area termed the Abermusden Area (coined from the names of the towns Aberdeen, Muswellbrook and Denman) by means of a pipe-line. With rising post-war costs, it soon became evident that this scheme was hopelessly uneconomic, and in 1953 the W.C. & I.C. commenced hydrogeological investigations of this section of the valley to ascertain the potential of its groundwater resources and the degree to which a regulated stream flow (in a river very prone to ceasing flow in dry periods) would permit increased irrigation development from these sources. It was found that there was considerable potential for further irrigation development, under existing conditions, and that the recharge induced when the water table was lowered below river level would permit additional expansion. However, encroachment of saline groundwater from flanking rock formations was also likely under lowered water table conditions, so that the situation would require careful observation and control as development proceeded.[23] Periodic checks on groundwater levels and salinity are being maintained in this regard.

The fact that Glenbawn Dam was being constructed did not satisfy the requirements of the valley, and there was an awareness of the need for an integrated plan to deal with the various conservation problems of the Hunter River basin as a whole. This concept started to take shape with the recommendation of the Hunter River Flood Mitigation Committee in 1947 (termed the "Huddleston Report") that an authority should be established with power to arrange for construction, maintenance and finance of proposed conservation and flood mitigation works, and that a small tax be applied to all lands in the valley. After a

[23] Williamson, W. H., 1958, "Groundwater Resources of the Upper Hunter Valley", W.C. & I.C., Government Printer, Sydney.

number of meetings by an interim committee, legislation was drafted, which, with minor variations, became the Hunter Valley Conservation Trust Act of 1950. Accordingly, the Trust was constituted, and held its first meeting in December, 1950.

As stated by Hawke[24] "The Trust's existence is based on the principle that the complete catchment of a river system is the ideal unit for conservation practices; that a flood mitigation programme cannot be completely divorced from proper conservation practices; and that cooperation between valley landholders, local organizations and State Departments is essential if ultimate success is to be achieved". To this end, the Trust is composed of representatives of the Conservation Authority, Departments of Agriculture and Public Works, Forestry Commission, Soil Conservation Service, W.C. & I.C., local Councils and landholders. It is not a constructing authority, but is empowered to raise funds by rating lands and uses such funds in subsidizing approved projects, both of a major nature and on individual properties. Although its interests cover a variety of conservation aspects, their ultimate purpose is directed not only to more effective use of the resources of the catchment, but also to flood mitigation. No doubt it will serve as a model for the formation of similar authorities in other drainage basins.

The Trust seems to have been formed at a rather appropriate time because from 1949 the valley experienced a series of floods, culminating in the disastrous February, 1955 flood, estimated to have caused a total damage and loss of the order of $25 million. Consequently, it has had little difficulty in obtaining cooperation.

Following these floods, further emphasis was placed on flood mitigation by the enactment of the Hunter Valley Flood Mitigation Act in 1956, with the W.C. & I.C. the constructing authority in non-tidal sections and the Department of Public Works in tidal sections. This resulted in the Hunter Valley receiving the most intensive programme of river improvement (q.v.) and flood mitigation works of any drainage basin in Australia, and the Trust was required to meet 25% of the cost. Later, through the New South Wales (Flood Mitigation) Act, 1964, the Commonwealth made $5½ million available to subsidize the State on a dollar-for-dollar basis on a six-year programme of flood mitigation works in six coastal streams of New South Wales, including the Hunter, and the Trust was required to meet one-seventh of the capital costs and 25% of maintenance costs of these works in the valley.

[24] Hawke, W. C., 1967, "Conservation of Soil, Water and Forests and Flood Mitigation in the Hunter Valley", Seventh Annual Conference of Flood Mitigation Authorities in New South Wales, Hunter Valley Conservation Trust, Maitland.

The Trust operates over the whole of the Hunter catchment with the exception of the City of Newcastle. A Bill to include Newcastle in the Trust district was defeated in the Legislative Council in 1966.

The 1955 floods also emphasized the need for research into hydrologic aspects specific to the Hunter catchment, and the Hunter Valley Research Foundation was formed that year with this aim. Initially, the Foundation concentrated on water resources studies, collecting hydrologic data, determining the hydrologic characteristics of streams, examining weather patterns, and the patterns and effects of floods and droughts. However, it soon became apparent that the problem was one requiring the examination of the total resources and investment structure within the valley, and the Foundation's activities took on a much wider scope, though still primarily oriented towards water resources. Either of itself, or with the cooperation of State and Commonwealth authorities, the Foundation has undertaken many research projects and has issued many publications. One of the most recent of these is an ambitious and far-reaching "Plan for Water Resources Development in the Hunter Valley".[25]

There is no doubt that the Hunter is the most "water conscious" of the State's coastal valleys, and McMahon[26] gives some interesting figures on its water usage. He estimates fresh water usage for the region for 1962 as 110,000 acre-feet (roughly thirty thousand million gallons) of which 54% was for irrigation, 22% domestic, 15% industry and 9% animal consumption. The area under irrigation is estimated to have been 37,500 acres, of which 22,500 acres were irrigated from streams and the remainder from groundwater. He further emphasizes the importance of groundwater, pointing out that 40% of the valley's irrigation, domestic and industrial requirements come from this source, mainly from the alluvium of the river and its tributaries and from the sandbeds extending along the coast from the river to Port Stephens.

The latter sandbeds are of particular interest from a water resources viewpoint, and have played a major role in Newcastle's water supply. The sandbeds are essentially extensive areas of ancient sand dunes now largely fixed by vegetation and occurring near the mouths of most of the major coastal rivers and in other areas along the coast. They are a particularly favourable source of good quality groundwater, and are readily recharged by rainfall. (Being so close to the sea, it is

[25] Renwick, C., Pattison, A., *et al.*, 1965, "A Plan for Water Resources Development in the Hunter Valley", Hunter Valley Research Foundation, Newcastle.

[26] McMahon, T., 1965, "Irrigating the Alluvium of the Hunter Valley", Monograph No 21, Hunter Valley Research Foundation, Newcastle.

a common fallacy that the fresh water in these sands is filtered sea-water!)

Of these coastal sands, the Tomago Sandbeds, near Newcastle, are by far the most intensively developed for their groundwater resources; in fact, apart from these and the Botany Sandbeds in the Sydney area, from which some ten million gallons per day are extracted for industrial use, relatively little demand is made on these water sources.

The Tomago Sandbeds had been known as a source of fresh water almost from the beginning of settlement at Newcastle. In his detailed history of the Hunter District Water Board, Armstrong[27] records pumps being installed in wells in the sands to obtain water for sale to sailing ships. However, Newcastle did not commence utilizing the sands as a source of town supply until 1939, although preliminary investigations had been undertaken in the early 1920's.

Up until 1885, Newcastle did not have a reticulated water supply, and was dependent on public and private wells. In that year, the Walka Waterworks were brought into operation, pumping water drawn from the Hunter River upstream of Maitland by pipeline to Newcastle. The scheme was operated by the Government until 1892, when the Hunter District Water Supply & Sewerage Board was constituted. As had been the case in Sydney, population growth, increased water demands, and drought periods, ultimately required a larger and more reliable source, and a scheme involving a dam on the Chichester River was approved by the Government in 1916. The dam was completed in 1924 and the Walka Waterworks were used only as a stand-by for many years until finally closed down.

When further extension of Newcastle's water supply became necessary, in 1936 the Board started on a scheme to obtain water from the Tomago Sandbeds. Two pumping stations were operating by 1939, and provision made for another two. However, drought caused an alarming depletion of Chichester Dam storage, and the number of pumping stations on the Tomago Sandbeds was increased to fifteen. All of these were operating by the end of 1941 and the capacity of the scheme was then 15 million gallons per day. Since then, a further five stations have been installed.

The pumping stations draw the water from batteries of gravel-packed tube-wells, utilizing centrifugal pumps. Since this system imposes a limit on the level to which the water table can be drawn down, some of the stations have been converted to use deeper bores and deep-bore pumps, the first of these being installed in 1952. Consider-

[27] Armstrong, J., 1967, "Pipelines and People" (the History of the Hunter District Water Board), Halstead Press, Sydney.

able care is required in operating coastal sandbeds as a major water source, for there is the danger of causing intrusion of sea-water if over-developed. Consequently, close watch is kept on water levels and salinities in a network of observation bores in the sands.

When even further expansion of Newcastle's supply became necessary, a number of schemes were examined, including a dam at Tillegra, on the Williams River, and the artificial recharge of the Tomago Sandbeds. The scheme finally adopted, termed the Grahamstown Water Supply Scheme, involves a weir on the Williams River, a three-mile canal, a major pumping station, a 4,000-foot tunnel, and then a canal into Grahamstown Reservoir. What must be virtually a unique feature of the scheme is the fact that the reservoir formed by damming Grahamstown Moor is flanked on one side by sandbeds, whereas reservoirs are normally hoped to be more or less water-tight. The redeeming feature in this case is that the sands are the Tomago Sandbeds, already developed as a water source, so that any leakage into them is effecting recharge and, in any event, can be readily intercepted.

Construction of the Grahamstown scheme began in 1956, and in 1957 W.C. & I.C. personnel and plant from the completed Glenbawn Dam were employed to construct the embankment and other works, completing their task in 1962. The scheme was officially opened in 1964, but there are still some phases to be completed, one of the advantages of the scheme being that it could progress in stages. When completed, a supply of some 60 million gallons per day will be available from Grahamstown storage to supplement supplies from Chichester Dam and the Tomago Sandbeds.

### The Water Research Foundation of Australia

Since its inception, the School of Civil Engineering in the University of New South Wales had been strongly oriented towards hydrology, and its Foundation Professor, C. H. Munro, had long been critical of the neglect of water resources, research and investigation in Australia. In a public symposia series at the University, the 1955 topic was "The Water Resources of Australia" and, with the disastrous and widespread February floods still fresh in the public mind, the occasion of this symposium was chosen to launch the Water Research Foundation of Australia.

The aims of the Foundation are "to initiate, promote and further scientific and technological research into the development, control and use of the water resources of Australia". Dependent mainly on financial support from private enterprise and the public, from a small beginning the Foundation has gradually expanded, and has done much to foster interest in water resources, research and investigation. With research committees draw from Government and semi-Government authorities, and from private enterprise, to examine and recommend on proposals, grants are made to assist approved research projects. Some $350,700 has been dispensed in this regard as at 1966 (Water Research Foundation of Australia, 1966), and bulletins and reports on its research projects have been published by the Foundation.

## Investigations of Groundwater Resources of Inland Drainage Systems

In view of the history of recurrent droughts, and the dependence placed on groundwater supplies, particularly in drought periods, it is rather surprising to find that up until 1957 systematic investigations of groundwater conditions had been virtually confined to the collection and collation of existing data, usually in conjunction with geological mapping. Probably the only significant exceptions to this are, firstly, the programme undertaken by the W.C. & I.C. in the alluvium of the Upper Hunter valley in relation to the use of Glenbawn Dam waters, commencing in 1953; secondly, the test-boring programme in the Botany Sandbeds in 1942 to establish their potential as an emergency water supply for Sydney during World War II; and thirdly, swamp drainage investigations in the estuarine flats of a few of the coastal rivers, such as the Macleay and Clarence, in the early 1900's. Consequently, knowledge on groundwater resources in the State was generally limited to the depths required for landholders to obtain stock-water supplies. Where irrigation was being carried out with groundwater, it was mostly in areas where shallow gravel aquifers, say to 60 feet, could be exploited by wells; and when boring was undertaken to search for irrigation supplies, exploration was usually confined to relatively shallow alluvial formations, rarely exceeding about 120 feet. Furthermore, yields from irrigation bores or wells rarely exceeded about 25,000 gallons per hour.

This was the situation when, on completion of the Upper Hunter investigation, the W.C. & I.C. commenced an investigation of the groundwater resources of the alluvium of the Lachlan River valley in late 1957. The Lachlan valley, one of the major inland drainage systems, was already served by the 304,000 acre-feet regulating storage of Wyangala Dam, completed in 1935. In addition, the en route storage of Lake Cargelligo, completed by the Department of Public Works in 1902, had been supplemented by a further en route storage, Lake Brewster, in 1952. Operation of Wyangala Dam, in conjunction with the en route storages, supplied water to more than 70,000 acres of licensed irrigation development along the river and its tributaries, as well as the Jemalong and Wyldes Plains Irrigation Districts, which

Burrendong Dam, on the Macquarie River, N.S.W. Constructed by the Water Conservation and Irrigation Commission.

contain over 30,000 acres of irrigated land. However, it was clear that there was far more irrigable land in the Lachlan valley than could ever be served by surface water projects. Consequently, the groundwater investigation was aimed particularly at ascertaining the potential for irrigation development from this source.

After preliminary mapping and data collection, a programme of test-boring to rock basement in representative cross-sections of the valley and its major tributaries was commenced, starting at Cowra and working downstream. The alluvium was found to consist of two distinct formations, both containing water-bearing sand and gravels. An intriguing aspect was that, although in the same valley and hence, one would expect, derived from the same catchment, the composition of the gravels in the two formations was quite different. Those in the uppermost formation (named the Cowra Formation) contained representatives of the resistant rock types in the present catchment, whilst those in the lower formation (named the Lachlan Formation) consisted of quartz gravels. Interbedded in the lower formation, too, were carbonaceous clays which contained fossil pollen, and these revealed that the vegetation in the area at the time of deposition some two million years previously (Late Pliocene) was rain forest! To explain the different composition of the gravels in the two formations, it was postulated that the present catchment had previously been blanketed with earlier Tertiary sediments which were the source material for the Lachlan Formation. After uplifts and erosion, the rocks of the present catchment were exposed and became the source material for the Cowra Formation.[28]

These findings are of considerable significance because, prior to the investigation, groundwater extraction, and the limited exploration undertaken for irrigation supplies, had been virtually confined to the Cowra Formation. This extends to about 120 feet, and has a relatively limited groundwater potential, yields of irrigation bores not often exceeding 20,000 gallons per hour. However, the sand and gravel beds of the Lachlan Formation are generally much thicker and more productive, and bores with screens exposed to only part of the available aquifers have yielded up to 100,000 gallons per hour. With appropriate techniques there is no reason why larger yields could not be obtained.

The depth of alluvium in the valley has been found to range from about 240 feet near Cowra to 450 feet near Forbes, and an important aspect is that the deepest section, within which the aquifers of the Lachlan formation are mainly developed, is entrenched into the floor

[28] Williamson, W. H., 1964, "The Development of Groundwater Resources of Alluvial Formations", Paper B11, in "Water Resources, Use and Management", University Press, Melbourne.

of an older and much wider valley, i.e., a buried "valley-in-valley". This means that although the alluvium may be very extensive, the most productive aquifers may be confined to a limited zone, corresponding to the entrenched section of the valley basement. Because of these conditions, the geophysical technique known as seismic refraction has been found of particular advantage in these investigations, both for "filling-in" data between drilled cross-sections, thus allowing tracing of the buried valley, and to guide the location of drilling in the more extensive areas. Some of the latter may be perhaps 20 or more miles wide, and have rock "islands" projecting through the alluvium, so that there are a number of alternative courses the buried valley could have taken.

At this writing it has been established that high yields and satisfactory water quality can be obtained from the alluvium from Cowra almost to Condobolin, some 120 miles downstream. The water quality then deteriorates, becoming too saline for irrigation or town supply, but an intriguing aspect is that 100 miles or so downstream, the groundwater is of good quality. This low salinity persists over a large fan-shaped area extending beyond the Lachlan Range for some 30 miles or so below Hillston, where the quality again deteriorates. Yields of over 120,000 gallons per hour have been obtained from bores to about 350 feet in the latter area. The change from poor to good quality groundwater upstream of the Lachlan Range is believed to be due to a new set of intake conditions provided by warping and/or faulting, and is to be investigated in the near future.

The length of that part of the Lachlan valley warranting investigations as to the potential of its groundwater resources for irrigation development thus extends from Cowra to some thirty to forty miles beyond Hillston, a distance of about 300 miles. Within this, the alluvium ranges in width from a few miles to thirty or more miles, and depths to about 500 feet. Not all is favourable, and there are many problems in the development of these resources, including that of flanking saline waters. At this stage, the investigations are aimed at establishing the broad conditions, with detail and more quantitative aspects to follow as development proceeds. However, it is evident that the groundwater resources of the Lachlan valley offer substantial potential for irrigation development, though not on the scale of irrigation areas.

The Lachlan valley has been dealt with in some detail, not only because it is the first of such valleys in the State to be systematically investigated, or because the investigation has revealed important water resources hitherto unknown, but also because the principles established have been found applicable to other major inland drainage systems. However, so far as is known, none of the others have an intervening zone of poor quality water as described for the Lachlan.

A similar investigation was commenced in the Namoi valley in 1963, and this valley too, in which previous groundwater development had been largely confined to shallow aquifers, has considerable resources in deeper formations. An important development has been the rapid growth of the cotton industry in the Narrabri-Wee Waa area, commencing with 97 acres in 1959 and initially based on irrigation from the river. In the drought conditions of the 1964-1965 season, when some 15,000 acres had been planted, there was intense activity to obtain alternative sources of water. A fair degree of success was achieved, and irrigation with groundwater is now an important factor, some bores yielding over 150,000 gallons per hour. Because of the heavy and rapidly expanding demand on groundwater in this area, the quantitative aspect is now receiving close attention by the W.C. & I.C. to avoid over-development.

It is clear that the alluvia of the inland drainage systems of the State offer the main source of large supplies of groundwater of quality suitable for irrigation, and for this reason the W.C. & I.C. is concentrating on these systems in its groundwater investigation programme. Apart from the inland valleys, with the exception of the shallow and more limited areas of fluviatile alluvium in some of the coastal streams, and a few limited areas in some of the sandstones of sedimentary basins, the groundwater resources of the remainder of the State are essentially of stock-water potential. In fact, in large areas the available groundwater quality is too saline even for sheep.

## Post-1960 Developments

Although there had been an obvious upsurge in water developments subsequent to World War II, events moved even more swiftly, almost "mushrooming", from about 1960.

On the groundwater side, the general need to consider the problems from a national aspect revived one of the recommendations of the 1939 Interstate Conference and led to the formation of the Underground Water Conference of Australia. The inaugural meeting to form the Conference was held in Sydney in June, 1959, and the first permanent meeting convened in Canberra in 1961, appropriate authorities from all States and the Commonwealth being represented. The Conference provided for an annual meeting of officers from the principal departments and authorities responsible for the research into, the conservation of and development of underground water in

Australia, and, unlike the series of Interstate Artesian Conferences ending in 1928, did not confine itself only to the problems of artesian basins.

However, there was also an awareness of the need for a national approach to water problems in all aspects. To meet this need the Australian Water Resources Council was formed late in 1962 and held its first meeting in March, 1963. Subsequent to this, the Underground Water Conference of Australia, which had held annual meetings since 1961, was dissolved and reconstituted in 1964 as the Technical Committee on Underground Water to act as an advisory committee to the Water Resources Council. A similar body, the Technical Committee on Surface Water, was formed to deal with and advise on surface water aspects. The Council itself consists of Commonwealth and State Ministers, and is serviced by a Standing Committee which is aided by the technical committees.

The principal objective of the Council is "the provision of a comprehensive assessment on a continuing basis of Australia's water resources and the extension of measurement and research so that future planning can be carried out on a sound and scientific basis". The initial step in meeting this objective was to have each State prepare a review of its surface and groundwater resources as at 1963. New South Wales authorities, as did other States, set about this task, and, for the first time a review of what was known of the State's total water resources was compiled. The efforts of the various States were then collated and published as a "Review of Australia's Water Resources, 1963" (Australian Water Resources Council, 1965). A major contribution in the Review is the presentation of the first meaningful map of Australia's groundwater resources, the New South Wales information being compiled by officers of the W.C. & I.C. and New South Wales Geological Survey.

The compilation of the Review immediately pointed to the marked lack of data in many areas, and to assist in achieving more complete knowledge of the extent and potential of water resources, the Commonwealth Government passed the State Grants (Water Resources) Act in 1964. The purpose of the Act is to encourage the States to implement accelerated programmes of research and investigation into surface and groundwater resources, and finance is made available by way of subsidy from the Commonwealth on the formula of two pounds for every three expended over a base figure (the 1963 expenditure), initially for a three-year period. Consequently, water resources investigations in New South Wales have been markedly increased in tempo, but a limiting factor has been the shortage of technical personnel. This has particularly been the case in the field of groundwater in which there is no appropriate educational course at graduate level in Australia —a matter which is causing considerable concern to the Technical Committee on Underground Water.

In the hydrographic field, additional river gauge stations have been installed to obtain data necessary for assessment of surface water resources, bringing the total number of gauge stations operating in the State to about 760 as at June 30, 1966. Of these, 677 are operated by the W.C. & I.C. (including 129 on behalf of other departments and authorities) and the remainder by other authorities such as the Water Board, the Snowy Mountains Authority and the University of New South Wales. Notable too, are the 38 flood warning stations operated by the W.C. & I.C. on behalf of the Bureau of Meteorology, the first of the Bureau's flood warning systems being completed in the lower Macleay valley. A significant step forward in the early 1960's was the publication of stream flow records by the W.C. & I.C., the first published comprehensive collation of such data, covering the information on hand up to 1950.

The importance of water was further emphasized in 1963 when the Australian Academy of Science held a national symposium on "Water Resources Use and Management". From its inception in 1954, the Academy was concerned at the deficiencies in hydrology in Australia, and one of its earliest actions was to arrange for a technical conference, convened in 1955, to consider the status of hydrology in Australia. As a consequence, a Standing Committee for Hydrology was constituted by the Academy the following year. Later, when it became known that moves were being made to form the Australian Water Resources Council, the Academy considered it a fitting time to arrange a national technical symposium on water-resources, use and management, as a means of establishing closer links between the considerable range of disciplines involved. The symposium was held at Canberra in September, 1963, and some forty papers were presented, covering such fields as the national outlook, basic data (precipitation, evaporation, surface water, underground water and data processing), the water balance (principles and research, and operation and management), socio-economic problems, and investigation and research. The papers and discussions on them were subsequently published[29] and constitute a very valuable record of what is no doubt one of the most important symposia held in Australia.

The 1960's also saw the fruition of a number of post-war developments, markedly altering the situation with regard to major storages in the State. In terms of water conservation and irrigation works,

[29] Australian Academy of Science, 1964, "Water Resources, Use and Management", University Press, Melbourne.

Glenbawn Dam, on the Hunter, had been completed in 1957, only a few years previously. Then followed Keepit Dam on the Namoi, a 345,000 acre-foot storage, completed in 1960, and regulating about 29% of the average annual yield of the Namoi basin. (So rapid was the increase in licensed irrigation, particularly because of the development of the cotton-growing industry in the Narrabri-Wee Waa area, that the waters of the dam were fully committed within a few years.) The Menindee Lakes Storages, providing an en-route storage adjacent to the Darling River, was also completed in 1960. The enlargement of Hume Reservoir, on the Murray, to double its capacity to 2½ million acre-feet was completed in 1961, and a few years later works were put in hand to enlarge Wyangala Dam, on the Lachlan. (Placement of the new earth and rock-fill embankment for this project was commenced in 1965.) By 1966, Burrendong Dam, on the Macquarie, was near completion, and, in fact, had been ready to store water since March, 1965. These works, taken with Warragamba Dam, and the major dams completed or under construction in the Snowy Scheme, made the decade up to 1966 by far the most outstanding in the history of the State in its achievements in water storages.

Blowering Dam, on the Tumut River, is under construction at this writing, and on its completion the regulation of the Murrumbidgee will have advanced from 45% to about 71% of the average annual yield, about the same as for the Murray system. These two streams are, of course, the most favourable in the State for irrigation, other streams not having the same advantages in terms of water availability and economics of major water schemes. Consequently, having regard for the provisions already made by major dams constructed or under construction on other streams, there is now a trend away from establishing further State-sponsored irrigation areas or districts, and towards serving the numerous streams not yet having the benefit of headwater storages to regulate their flows. To "take stock" and review these requirements, in late 1965 the W.C. & I.C. embarked on a comprehensive assessment of the water resources of thirty river valleys throughout the State. The reports on the valleys would then be used as a basis for the planning and future development of the State's water resources. As at June, 1966, reports had been published on the Bega and Richmond valleys and a further three (Macintyre, Severn and Gwydir) were in preparation for publication.

In April, 1966, the Minister for Conservation issued a report on a Preliminary Proposal for the Expanded Development of the Water Resources of New South Wales, which sets out tentative long-term and short-term programmes. The proposals include the construction of a regulating storage on each major stream as soon as possible, as well as increased expenditure on farm dams and groundwater and irrigation developments, and aim at more than doubling the water resources at present available under some form of regulation or on-farm storage within the State. Commonwealth assistance is being sought to augment the finances available to implement the programmes, to bring the time aspect into reasonable limits.

In the meantime, a preliminary five-year programme for implementation of surface water conservation works, to be financed from loan funds anticipated to be available from 1966-1967 to 1971-1972, includes such works as the completion of Burrendong, Wyangala and Blowering Dams, the construction of the first stage of Pindari Dam on the Severn River, and the first stage of a dam on the Gwydir River. (Staged construction will avoid tying up the huge capital investment involved in constructing the largest dam practicable on a given site. The first stage would meet the demands of existing development with a margin for expansion, and when the regulated flow from the first stage storage is fully committed, the second stage can be undertaken.) The programme also includes commencement of a storage on the Belubula River in the Lachlan valley, and on the Patterson River in the lower Hunter valley.

With these moves afoot, and the ever-increasing activities in all phases of the field of water over the preceding decade, the future of water development in New South Wales augurs well. Furthermore, in this age of scientific and technological achievement, it does not seem too much to hope for successful outcomes to the large amount of research being undertaken on such aspects as evaporation control, transpiration suppression, desalination and rain-making. It seems fitting that we should be entering the 1965-1975 International Hydrologic Decade. Perhaps, at last, man's most basic requirement—water—will receive the attention it deserves.

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