CHAPTER 22

WATER CONSERVATION AND IRRIGATION

RESOURCES, UTILISATION AND NATIONAL AND INTERSTATE ASPECTS

Official Year Book No. 51, pages 228–31, contains a description of recent developments in the measurement of Australia's water resources. For information concerning general, descriptive and historical matter *see also* Year Book No. 37, pages 1096–1141.

For further details on geographical and climatic features determining the Australian water pattern, *see* the chapter Physical Geography and Climate; on water supply and sewerage in metropolitan areas, cities and towns, the chapter Local Government; and on the generation of hydro-electric power, the chapter Electric Power Generation and Distribution, of this issue.

A series of maps showing the location of major dams and reservoirs and the various irrigation schemes operating in each of the States may be found on pages 259–65 of Year Book No. 46, and a map showing the extent of known artesian basins throughout Australia is shown on page 273 of Year Book No. 48.

Water resources and their utilisation

Surface supplies

An assessment of Australia's surface water resources has been made, based on measured and estimated stream flows within 197 river basins, as follows. The total average annual discharge of Australian rivers has been assessed at 280 million acre feet. This can be divided into 108 million acre feet measured discharge and 172 million acre feet estimated for areas where there are generally no gauging records. For the whole area of Australia (approximately 3 million square miles) only 1.9 million square miles are regarded as contributing to stream flow (i.e. there is practically no flow from Western Plateau drainage division and from arid parts of other divisions).

The flow of Australian rivers is small in comparison with the flow of rivers in other continents, some examples of which, expressed as mean annual discharges in millions of acre feet, are: Amazon, 2,950; Mississippi, 465; Mekong, 405; Niger, 308; Volga, 205; and the ten major rivers of the United States of America in the aggregate, 900.

Major dams and reservoirs

The table below lists existing major dams and reservoirs, together with those under construction and those projected, at June 1967. The list is confined to dams and reservoirs with a capacity of 100,000 acre feet or more. There are many others of smaller capacity in Australia.

MAJOR DAMS AND RESERVOIRS IN AUSTRALIA

Name	*Location*	*Capacity (acre feet)*	*Height of wall (feet)*	*Remarks*
EXISTING DAMS AND RESERVOIRS				
Eucumbene	Eucumbene River, New South Wales	3,890,000	381	Part of Snowy Mountains Hydro-electric Scheme
Eildon	Upper Goulburn River, Victoria	2,750,000	260	Storage for irrigation and for the generation of electricity
Hume	Murray River, near Albury, New South Wales	2,480,000	142	Part of Murray River Scheme—storage for domestic stock and irrigation purposes. Hydro-electric power also developed
Menindee Lakes Storage	Darling River, near Menindee, New South Wales	2,000,000	..	Part of Darling River Water Conservation Scheme
Miena	Great Lake, Tasmania	1,710,000	60	Storage for Poatina hydro-electric power station
Warragamba	Warragamba River, New South Wales	1,670,000	379	For Sydney water supply. Also provides for generation of hydro-electricity and flood mitigation

MAJOR DAMS AND RESERVOIRS IN AUSTRALIA—*continued*

Name	*Location*	*Capacity (acre feet)*	*Height of wall (feet)*	*Remarks*
EXISTING DAMS AND RESERVOIRS—*continued*				
Burrendong	Macquarie River, near Wellington, New South Wales	1,361,000	250	Storage for rural water supplies
Burrinjuck	Murrumbidgee River, New South Wales	837,000	264	Storage for irrigation and production of hydro-electric power
Somerset	Stanley River, Queensland	735,000	173	Brisbane–Ipswich water supply, flood mitigation and small hydro-electric power station
Jindabyne	Snowy River, New South Wales	558,000	235	Part of Snowy Mountains Hydro-electric Scheme
Lake Victoria	Murray River, near South Australian border, in New South Wales	551,700	..	Natural off-river storage for irrigation in South Australia. Storage improved by construction of embankments and control regulators
Lake Echo	Lake Echo, Tasmania	442,000	60	Storage for Lake Echo, Tungatinah, Liapootah, Wayatinah and Catagunya hydro-electric power stations
Clark	Derwent River, Tasmania	434,000	220	Storage for Tarraleah, Liapootah, Wayatinah, and Catagunya hydro-electric power stations
Arthur Lakes	Source of Lake River, near Great Lake, Tasmania	410,000	50	Part of Great Lake hydro-electric power development
Keepit	Namoi River, near Gunnedah, New South Wales	345,000	177	For rural water supplies and hydro-electricity generation
Waranga	Goulburn River, Victoria	333,400	45	Irrigation storage
Tinaroo Falls	Barron River, North Queensland	330,000	136	For irrigation purposes in the Mareeba-Dimbulah area
Glenbawn	Hunter River, near Scone, New South Wales	293,000	251	Part of Hunter Valley conservation work, for irrigation and flood mitigation
Rocklands	Glenelg River, Victoria	272,000	93	Part of Wimmera-Mallee domestic and stock water supply system
Eppalock	Campaspe River, near Heathcote, Victoria	252,860	150	To supplement supply to Bendigo and for irrigation
Wyangala	Lachlan River, New South Wales	(*a*)245,000	200	Storage for domestic, stock and irrigation purposes and for generation of hydro-electric power. (*See also* under Dams and Reservoirs under Construction)
Tantangara	Murrumbidgee River, New South Wales	206,000	148	Part of Snowy Mountains Hydro-electric Scheme
Avon	Avon River, New South Wales	(*a*)163,390	232	Part of Sydney water supply
Upper Yarra	Yarra River, Victoria	162,000	270	For Melbourne water supply
Glenmaggie	Gippsland, Victoria	154,300	121	Storage for irrigation
Lake St Clair	Central Highlands, Tasmania	154,200	..	Improved natural storage for Tarraleah hydro-electric power station
Wellington	Collie River, Western Australia	150,100	112	For supply of water to irrigation districts and to agricultural areas and country towns
Grahamstown	Grahamstown River, near Newcastle, New South Wales	147,000	35	To supplement supply to Newcastle and district
Koombooloomba	Tully River, North Queensland	146,000	123	For hydro-electric and irrigation purposes
Serpentine	Serpentine River, Western Australia	144,000	171	For Perth water supply
Lake Brewster	Lachlan River, near Hillston, New South Wales	123,900	..	Storage of rural water supplies for the lower Lachlan
Cairn Curran	Loddon River, Victoria	120,600	144	Storage for irrigation
Rowallan	Mersey River, North Tasmania	110,000	140	Storage for Mersey Forth power development
DAMS AND RESERVOIRS UNDER CONSTRUCTION				
Blowering	Tumut River, New South Wales	1,320,000	368	For regulation of discharges from stations of Snowy Mountains Hydro-electric Scheme, primarily for irrigation but also for hydro-electric power generation
Wyangala	Lachlan River, New South Wales	1,000,000	270	Strengthing and enlarging of existing dam for increased water supply and hydro-electric power generation. (*See also* under Existing Dams and Reservoirs)
Wuruma	Nogoa River, Central Queensland	157,000	120	For irrigation storage
Eungella	Broken River, North Queensland	104,000	150	Provision of cooling water for Collinsville power station and for irrigation purposes

(*a*) Temporary reduced level.

MAJOR DAMS AND RESERVOIRS IN AUSTRALIA—*continued*

Name	*Location*	*Capacity (acre feet)*	*Height of wall (feet)*	*Remarks*
DAMS AND RESERVOIRS PROJECTED				
Gordon	Gordon River, South-west Tasmania	9,600,000	450	Storage for Gordon River power development
Chowilla	Murray River, in South Australia, near Victorian border	(*a*)5,000,000	41	Regulation of the lower Murray River
Ord River (main)	Near Wyndham, Western Australia	4,600,000	220	For irrigation, generation of hydro-electric power and flood mitigation. (additional 6,000,000 acre feet flood control proposed)
Maraboon	Nogoa River, Central Queensland	1,170,000	148	For irrigation and probable thermal power station
Copeton	Gwydir River, New South Wales	1,100,000	373	For irrigation storage
Buffalo (second stage)	Buffalo River, near Myrtleford, Victoria	800,000	260	For irrigation
Talbingo	Tumut River, New South Wales	747,000	530	Part of Snowy Mountains Hydro-electric Scheme
Warkworth	Wollombi Brook, Hunter Valley, New South Wales	406,000	130	Flood mitigation and irrigation dam for Hunter Valley
Serpentine	Serpentine River, south-west Tasmania	307,200	135	Storage for Gordon River power development
Scotts Peak	Huon River, south-west Tasmania		160	
Mokoan	Winton Swamp, near Benalla, Victoria	300,000	35	To store flood flows in Broken River for irrigation
Cardinia Creek	Near Emerald, Victoria	220,000	260	For off river storage for Melbourne water supply
North Pine	North Pine River, near Petrie, Queensland	164,000	125	To supplement supply to northern Brisbane area

(*a*) Subject to final survey.

Irrigation

For some brief remarks on the history of irrigation in Australia *see* issues of the Year Book prior to No. 39. Trends in irrigation practice in more recent years were described in Year Book No. 37, page 1099.

AREA OF LAND IRRIGATED, STATES AND TERRITORIES, 1962–63 TO 1966–67

(Acres)

Season and crop	*N.S.W.* (*a*)	*Vic.* (*b*)	*Qld*	*S.A.*	*W.A.*	*Tas.*	*N.T.*	*A.C.T.*	*Aust.*
1966–67—									
Cotton	22,218	..	7,997	..	11,892	..	..	..	42,107
Hops	..	(*c*)	..	..	(*d*)	1,495	..	..	(*e*)1,495
Orchards	35,562	46,594	(*f*)9,040	32,122	11,704	8,287	87	7	143,403
Rice	73,639	..	..	..	(*d*)	..	(*g*)	..	(*e*)73,639
Sugar-cane	(*c*)	..	142,620	..	..	..	..	..	(*e*)142,620
Tobacco	*n.a.*	*n.a.*	11,781	..	..	..	..	..	(*e*)11,781
Vegetables	16,639	26,617	39,198	12,341	9,770	12,979	178	117	117,839
Vineyards	17,935	47,418	(*h*)	28,268	795	..	..	..	(*e*)94,416
Other crops (including fodder and fallow land)	455,872	128,543	88,508	23,720	4,676	6,353	437	571	708,680
Total, crops	*621,865*	*249,172*	*299,144*	*96,451*	*38,837*	*29,114*	*702*	*695*	*1,335,980*
Pastures	818,916	1,064,716	44,908	42,306	31,790	18,111	188	459	2,021,394
Total, 1966-67	**1,440,781**	**1,313,888**	**344,052**	**138,757**	**70,627**	**47,225**	**890**	**1,154**	**3,357,374**
1965–66	1,308,439	1,262,661	332,534	128,835	67,407	45,196	771	1,125	3,146,968
1964–65	1,198,404	1,189,055	281,173	123,139	63,035	34,322	587	1,120	2,890,835
1963–64	1,060,479	1,137,241	252,082	117,870	55,194	33,570	973	1,081	2,658,490
1962–63	1,036,846	1,151,555	221,161	112,813	51,501	24,285	434	1,247	2,599,842

(*a*) *Source:* Water Conservation and Irrigation Commission. (*b*) *Source:* State Rivers and Water Supply Commission. (*c*) Not available separately; included in Other crops. (*d*) Not available for publication; included in Other crops. (*e*) Incomplete, *see* individual States. (*f*) Includes vineyards. (*g*) Not available for publication; excluded from totals. (*h*) Included with Orchards.

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Irrigation research

Comprehensive programmes of research and investigation are being pursued by State water and agricultural authorities and the Commonwealth Scientific and Industrial Research Organization, often in collaboration. Special attention is being given to the following: high water tables due to the application of water; surface accumulation of salt and other soil changes associated with irrigation; methods of applying water efficiently; soil treatments to improve the physical condition of irrigated heavy clay soils; the utilisation of irrigated pastures by stock; growth problems affecting plants and trees; the prevention of evaporation from water storages; the potability of saline waters for stock; the de-salting of brackish waters; and cloud-seeding over catchments.

Irrigation is studied by the Commonwealth Scientific and Industrial Research Organization at a number of its research stations and laboratories, the principal one being the Division of Irrigation Research at Griffith (New South Wales), where investigations are concerned with limiting the degradation of land by irrigation, improving the quality and range of irrigated crops, and assessing the amount of water required by irrigated crops and the most economical means of applying it. The crops being studied include citrus, cotton, wine grapes and lucerne. The Organization's Division of Plant Industry studies irrigated pastures at Deniliquin (New South Wales) and Canberra (Australian Capital Territory), and tobacco at Mareeba (Queensland). At Adelaide (South Australia) and Merbein (Victoria) the Division of Horticultural Research is working on problems of the dried-fruit industry. The Division of Land Research conducts research on rice at the Coastal Plains Research Station, Darwin (Northern Territory), and on a number of irrigated crops, including rice, safflower, linseed, and cotton, at the Kimberley Research Station (Western Australia). The Division has also carried out a number of hydrological investigations in connection with the utilisation of underground water for irrigation. The Division of Soils and the Division of Soil Mechanics are studying methods of reducing seepage from earthen dams, and take part in the examination of the physical properties of sediments beneath proposed dam sites. The Division of Soils is also looking at underground water movement and the water balance in the south-east of South Australia, and at the drainage and soil moisture regime of the irrigated swamps of the lower Murray River. The Division of Applied Chemistry is investigating methods of minimising evaporation losses from water storages by the use of monomolecular layers.

The Irrigation Research and Extension Committee plays an important part in the agricultural activity of the Murrumbidgee and Coleambally Irrigation Areas. It is representative of the New South Wales Department of Agriculture, the Commonwealth Scientific and Industrial Research Organization, the Rural Bank of New South Wales, the Soil Conservation Service of New South Wales, the Water Conservation and Irrigation Commission, the Rice Marketing Board of New South Wales, and secondary industries' and farmers' organisations. Finance is provided by these authorities on an agreed basis. The objectives are: to enable the agricultural extension services to the farmers in the defined sub-region to be continued and developed; to provide a system for advising on local agricultural policy and organisation; to provide means for farmer opinion to have due weight in the consideration of regional agricultural administration and policy; to achieve a unified approach to sub-regional extension in all branches of agriculture; to advise on the research needs of the sub-region and to co-ordinate the agricultural research of the various rural institutions working therein; to achieve close liaison between research and extension; and to conduct research in extension methods.

Two other organisations with similar objectives are the Victorian Irrigation Research and Promotion Organisation which operates from Shepparton, and the Murray Research and Extension Committee centred at Deniliquin.

Preservation of catchments

Since water conservation commences on the catchments it is becoming increasingly recognised that anything which interferes with catchment efficiency affects the quantity of water available for all purposes. Active steps are being taken to counteract soil erosion, to conserve soil generally, and to minimise the effects of floods, overstocking, bush fires, and the destruction of vegetative cover. All States and the Commonwealth have initiated forestry policies which provide for reforestation and the preservation of catchments. In recent years efforts to counteract soil erosion have been intensified, and there is some evidence of a more unified approach to catchment, water, forestry, and land use factors regarded as parts of a single problem.

Sub-surface supplies

Much of Australia's underground water is obtained from artesian and sub-artesian basins and is used for stock purposes and domestic use. These supplies are indispensable in the dry areas which comprise most of the inland and extensive coastal areas as well. The quality of water ranges from

usable to very saline. The wide availability of saline waters or the proximity of the sea means that with modern desalination plants, several of which have already been installed, development opportunities are not necessarily impeded by lack of fresh water.

Considerable use is also made of sub-surface water, other than pressure water, from local storages, particularly in the well-settled areas. The water is used mainly for domestic and stock purposes. Compared with other countries with similar rainfall and climate, underground water is not used extensively for town and individual industrial supplies, but its use for these purposes is increasing.

Artesian and sub-artesian supplies. Pressure water (either artesian or sub-artesian), variable in quantity and quality, is obtainable in many parts of Australia, the various artesian basins extending over about half the continent. A map of Australia showing the extent of the known artesian basins appears on page 273 of Year Book No. 48.

The Great Artesian Basin, the most extensive in the world, underlies an area of approximately 676,250 square miles, comprising about 421,000 in Queensland, 135,000 in South Australia, 81,250 in New South Wales and 39,000 in the Northern Territory. A table setting out the principal defined water-bearing basins in Australia appears on page 1001 of Year Book No. 53.

More than 18,000 artesian bores have been drilled within the Great Artesian Basin, while the daily free discharge from all bores continuing to flow in Australia has been stated as exceeding 350 million gallons, of which the loss by evaporation and seepage has been estimated at more than 90 per cent. Sub-artesian bores and wells throughout Australia number more than 200,000.

Artesian water generally is good stock water, but most is unsuitable for plant life; in certain areas sub-artesian waters are suitable for all uses including irrigation. In the Eucla Basin and parts of the Murray and Pirie-Torrens Basins the water is of poor quality, being barely suitable for stock.

In common with other countries possessing artesian supplies, Australia has been faced with the problem of flow diminution. It was recognised early that flows were diminishing as more bores were drilled, but it is now considered that while many of these bores will ultimately cease to flow, others will assume a perpetually steady rate of flow, corresponding with the average intake of water from rainfall absorbed by permeable outcrops, mainly sandstone and limestone. Diminution in flows from artesian bores has emphasised the need to eliminate wastage as much as possible. Licences now issued for the construction of new artesian bores prohibit the distribution of water through drains, channels, etc., and the supplies must be confined to the borehead or piped to appropriate watering points.

Shallow groundwater. Shallow groundwater supplies are used in various parts of Australia for industry, irrigation, stock, and domestic purposes. Two examples of the use of these shallow supplies for industrial and domestic purposes occur in New South Wales. The Hunter District Water Board pumps 15 million gallons a day for general use from the Tomago coastal sands near Newcastle, and at Botany, Sydney, private industry pumps 8–10 million gallons a day for its own use from similar sands. Exploration of the coastal sands north of the Tomago Sands has revealed a further potential production of 25 million gallons a day. Examples of the use of shallow groundwater supplies for irrigation include the Burdekin Delta and the Bundaberg area in Queensland. In the Burdekin Delta, which covers an area of some 200 square miles, the present extraction for irrigation from underground sources is in the region of 200,000 acre feet per annum (about 150 million gallons a day) and in the Bundaberg area it is approximately 50,000 acre feet per annum (about 37 million gallons a day).

Schemes for artificial recharge of underground supplies have been implemented on both sides of the Burdekin River delta. Diversions from unregulated river flows of 61,000 acre feet per annum to the north side and of 40,200 acre feet per annum (when available) to the south side have been authorised.

In recent years there has been a marked increase, particularly in Queensland, New South Wales and Victoria, in investigation into the groundwater resources of river and coastal alluvium for irrigation and town water supplies.

National and interstate aspects

As the Commonwealth Constitution makes special reference to water rights, both the Commonwealth and the State Governments have an interest in the control and conservation of water. The main responsibility for control of water resources rests with the individual State Governments, but as political boundaries sometimes intersect river valleys and catchments, co-operation between Governments has been necessary to develop resources in certain cases. Specific examples of Commonwealth-State and interstate co-operation and approach are given in the following paragraphs.

Australian Water Resources Council

The Australian Water Resources Council was established by joint action of the Commonwealth and State Governments in 1962. The council comprises Commonwealth and State Ministers primarily responsible for water resources, with the Commonwealth Minister for National Development as Chairman, and is serviced by a Standing Committee consisting mainly of the heads of Departments responsible to these Ministers, and by a number of technical committees.

The primary 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 as to provide a sound basis for the planning of future development.

In terms of its main objective, the Council in 1964 recommended, and the Commonwealth and State Governments agreed, that there should be an accelerated programme of establishment of stream gauging stations and investigation of underground water. The Commonwealth Government agreed to contribute a total of up to $2,750,000 for the first three years of what was envisaged as a ten-year programme. The Commonwealth contribution for the current three-year period, which began in 1967-68, will be up to $4,500,000. In the first three years the States spent about $8,000,000 from their own financial resources, and expenditure in excess of this amount is expected in the current three years.

The Council has also given attention to the collation of available data on Australia's water resources, and in 1965 a *Review of Australia's Water Resources (Stream Flow and Underground Resources) 1963* was published. This document was the first official assessment of surface and underground water resources. In 1967 a catalogue *Stream Gauging Information, Australia, June 1965* was published on behalf of the Council by the Department of National Development. Water authorities have also agreed to publish stream flow records at five-yearly intervals. The Council continues to support Australian participation in the programme of the International Hydrological Decade (1965–1974). An important contribution will follow from the decision of the Council to select one hundred representative basins throughout Australia for detailed hydrological studies.

Studies of the requirements and facilities for education in the water resources field have been undertaken by the Council. Research studies in progress on a number of topics requiring urgent attention are being published in a new Australian Water Resources Council Hydrological Series, the first volume of which is *A Survey of Water Desalination Methods and their Relevance to Australia*, published in 1966.

The Council is not concerned with particular works projects, normally the responsibility of the States or the Commonwealth, for which there are established channels, such as the Premiers' Conference and Loan Council, for the exchange of views and allocation of funds.

National Water Resources Development Programme

In developing water resources, the Commonwealth Government's role in the past, while important, had been confined to assisting special projects or areas, e.g. the Snowy Mountains Scheme, participation in the River Murray Commission, and financial support for individual State projects such as the Ord River project. However, the National Water Resources Development Programme, announced in November 1966, represents a very important move towards closer collaboration between State and Commonwealth Governments, and a more continuing and detailed involvement by the Commonwealth in the development of Australia's water resources.

Under the National Water Resources Development Programme the Commonwealth has undertaken to provide grants to the States amounting to a total of about $50,000,000 over the next five years for water conservation works aimed at reducing the hazards of droughts and expanding primary production. The first two grants under this Programme were announced late in 1967. For the Emerald irrigation project in central Queensland, the Queensland Government is to receive a non-repayable grant of up to $20,000,000 for the construction of the dam, with the State financing the irrigation, drainage, and associated works. Two Victorian schemes to reduce salinity levels in the Murray River, for which grants totalling $3,600,000 will be provided, were approved as a matter of urgency so that the works can be constructed in time for the 1968–69 irrigation season.

Proposals submitted by the States are examined by the Commonwealth to determine which are suitable, from a national point of view, for inclusion in the Programme, and accordingly grants will be announced from time to time.

Murray River scheme

The Murray River and its tributaries form the largest river system in Australia. The catchment is approximately 408,000 square miles, or one-seventh of the area of the Australian continent, comprising five-sixths of New South Wales, over one-half of Victoria, one-sixth of Queensland and a small part of South Australia. The Murray proper is 1,600 miles long. Its main tributaries are the

Darling (1,700 miles), the Murrumbidgee (980 miles), and the Goulburn (350 miles). The average annual flow of each of the chief contributory streams is as follows: Upper Murray, including the Mitta Mitta and Kiewa Rivers, 3,820,000 acre feet; Darling River, 2,820,000 acre feet; Goulburn River (including Broken River), 2,580,000 acre feet; Murrumbidgee River, 2,050,000 acre feet; and Ovens River, 1,266,000 acre feet. Irrigated production in the Murray River Basin is mainly grapes for wine, dried fruits, fresh fruits, rice, vegetables, dairy produce, wool, and fat lambs.

River Murray Waters Agreement. For a brief summary of historical events leading up to the River Murray Agreement (1915) by the Governments of the Commonwealth, New South Wales, Victoria, and South Australia *see* issues of the Year Book prior to No. 39. Under the Agreement construction works are carried out by the States (which are also responsible for maintenance) subject to the approval and direction of the River Murray Commission. The Agreement provides that the minimum quantity of water to be allowed to pass for supply to South Australia in each year shall be sufficient to maintain certain specified flows in the lower river varying from 47,000 acre feet a month in the winter months to 134,000 acre feet a month in the four summer months of maximum demand—the total amounting to 1,254,000 acre feet over twelve months. The flow at Albury is shared equally by New South Wales and Victoria, and each of these States has full control of its tributaries below Albury, subject in each case to the fulfilment of the South Australian allocation. For a brief outline of the operation of the Agreement prior to 1949 *see* Year Book No. 40, page 1065, and earlier issues.

At a conference of Ministers held in 1949 to consider the diversion of the Snowy River it was decided that, by diversion of streams in the Snowy Mountains area, an average of approximately 440,000 acre feet per annum would be added to the Murray River (*see* Snowy Mountains Hydro-electric Scheme, page 967) and that increased storage should be provided in order to give additional regulation of the Murray River itself as well as to provide for regulation of the diverted waters. Hydro-electric potentialities would also affect the size of the storage.

The River Murray Commission investigated the position and subsequently recommended to the contracting Governments that the River Murray Waters Agreement be amended to provide for enlargement of the Hume Reservoir by 500,000 acre feet to approximately 2,500,000 acre feet. A conference of Ministers in 1954 agreed to the enlargement, and it was also agreed that the Commission should be given power to construct regulators and to carry out such other work on the Murray River between Tocumwal and Echuca as it considered necessary to reduce the losses from the regulated flow in that stretch of the river. The amended Agreement was ratified in the Parliaments of the Commonwealth and the three States and was proclaimed on 7 April 1955. In view of the proposed diversions by the Snowy Mountains Authority to and from the Murray River, and for other reasons, amendments to those sections of the River Murray Waters Agreement dealing with the distribution of the waters of the Murray were considered desirable. Following ministerial conferences, amendments were ratified by the four Parliaments concerned, and came into force on 6 November 1958.

Further amendment of the Agreement to provide for the construction of a storage of approximately 5,000,000 acre feet capacity at Chowilla in South Australia was ratified by legislation in the Commonwealth and State Parliaments and came into force on 30 April 1964.

As a temporary measure, to assist in drought mitigation pending development of this project, it has been agreed that portion of the waters in the Menindee Lakes storage will be made available to the Commission for allocation between the States of New South Wales, Victoria and South Australia. The arrangement, to operate for a period of seven years from 1 January 1963, was approved by the *Menindee Lakes Storage Agreement Act* 1963.

The quantity (in acre feet) of water diverted during 1966–67 from the Murray and its tributaries for irrigation and other purposes was as follows: New South Wales, 3,782,000; Victoria, 3,154,000; South Australia, 384,000; a total of 7,320,000 acre feet.

River Murray Works. One of the major works of the Murray River scheme is the Hume Reservoir, situated just below the junction of the Murray and Mitta Mitta Rivers, ten miles above Albury, forming a lake of 50,000 acres. The design comprises a mass concrete spillway and outlet works extending for 1,000 feet, and an earthen embankment 142 feet high extending for 4,000 feet across the river flats, the length of the total structure being approximately one mile. Work on the enlargement of the reservoir to its approved capacity of 2,480,000 acre feet was completed in 1961.

The Yarrawonga Diversion Weir, which was completed in 1939, raised the river level so that water could be diverted by gravitation into main channels constructed on either side of the river. Between the Yarrawonga Weir and the Murray mouth, thirteen weirs and locks have been built. Two flood diversion weirs have been constructed on the Murrumbidgee—one between Hay and the Lachlan junction and the other below the Lachlan junction.

The Mulwala Canal, supplied from the Yarrawonga Weir, has an off-take capacity of 2,500 cubic feet a second, servicing 1,800,000 acres of land in New South Wales. The Yarrawonga Channel, on

the Victorian side, has an off-take capacity of 1,250 cubic feet a second, serving 300,000 acres. Not all of this area is irrigated.

Adjoining the river in New South Wales, and 35 miles from the Murray-Darling junction, Lake Victoria storage, with a surface area of 27,670 acres, was completed in 1928. The water released from Lake Victoria is used by the South Australian settlements. The inlet channel to Lake Victoria was enlarged in 1957 to permit greater diversion of periodical flood flows of short duration.

Five barrages across channels near the Murray River mouth connecting Lake Alexandrina with the sea were completed in 1940 to prevent ingress of salt water to Lakes Alexandrina and Albert and to the lower river, thereby increasing the productivity of adjacent lands. The structures maintain a sufficiently high level for 50 miles up river to permit watering by gravitation of a considerable area of reclaimed river flats. The total distance across the barrages and intervening islands is 15 miles.

In addition to the works carried out under the auspices of the Commission, the separate States have constructed thousands of miles of distribution channels and have provided a number of storages on the tributaries, thereby contributing materially to the large amount of irrigation development in the Murray Basin. The main storages are: New South Wales—Menindee Lakes Storage (Darling), Burrinjuck (Murrumbidgee), Keepit (Namoi), Burrendong (Macquarie), and Wyangala (Lachlan); Victoria—Eildon (Goulburn), Waranga (Goulburn), Eppalock (Campaspe) and Cairn Curran (Loddon). Details of these and other State works on Murray tributaries will be found in the sections dealing with State systems. No storages exist on the Murray in South Australia at present, but the construction of a large storage at Chowilla is proposed (*see* page 965).

New South Wales-Queensland Border Rivers Agreement

The catchments for the border streams of New South Wales and Queensland (2,000 square miles) extend to the granite areas in the vicinity of Tenterfield (New South Wales) and Stanthorpe (Queensland), and elevation rises to 3,000 feet. Average rainfall is 30 inches. The catchments and the areas suitable for irrigation are approximately equal in each State. Climatic conditions are such that from April to October it is necessary to supplement rainfall by irrigation to stabilise and increase production. The capacity of the area to grow lucerne and tobacco under irrigation has already been demonstrated. Other possible development of the area includes irrigation of cotton, root crops, cereals, and citrus fruit, and expansion of the fat stock industry.

The New South Wales-Queensland Border Rivers Agreement came into effect on 1 July 1947. The Agreement provides for the construction of certain works on those sections of the Severn, Dumaresq, MacIntyre, and Barwon Rivers which constitute part of the boundary between New South Wales and Queensland for the furtherance of water conservation, water supply and irrigation in those States.

The works to be constructed comprise a dam on the Dumaresq River at a site to be selected by the Water Conservation and Irrigation Commission of New South Wales (the constructing authority) to give a storage basin with a capacity as large as is reasonably practicable and not less than six nor more than twelve weirs as may be found necessary to meet the requirements of irrigation along the rivers. Provision is also made for the construction of not more than four regulators in the effluents from the barrier rivers and for the taking over of the existing weir on the MacIntyre River at Goondiwindi and the existing weir on the Barwon River at Mungindi (the Irrigation and Water Supply Commission of Queensland is the constructing authority for new weirs and regulators). The cost of these works and of administration are to be borne by the States in equal shares. The Agreement further provides that the water discharge from the Dumaresq storage, whether by regulated or unregulated flow, shall be available to the two States in equal shares.

After unfavourable foundation conditions were disclosed at several dam sites on the Dumaresq River, investigations were extended to tributary streams, and superficially suitable sites located on Pike Creek and the Mole River. A geophysical survey was made at each of these sites and preliminary comparative estimates were prepared to determine the relative economy of providing one large storage at Mingoola or two smaller storages on the tributaries. Following exploratory drilling of the tributary sites, a report dealing with alternative storage proposals and possible amendments to the existing Agreement was submitted to the participating States. It was subsequently agreed by the State Governments that, at the appropriate time, the existing Agreement would be amended to include, *inter alia*, provision for the construction of storages on Pike Creek (Queensland) and the Mole River (New South Wales).

Completed works include Bonshaw and Cunningham Weirs on the Dumaresq River, a weir and regulator on the Barwon River at the offtake of the Boomi River, and a low level weir to establish a pumping pool at Glenarbon on the Dumaresq River. The existing Goondiwindi and Mungindi Weirs are being maintained, operated and controlled by the Queensland Irrigation and Water Supply Commission. Until a dam has been constructed it is unlikely that any other weirs will be required.

Snowy Mountains Hydro-electric Scheme*

Following a comprehensive investigation into both the water and power potential of the Snowy River waters by a Technical Committee representative of the Commonwealth and the States of New South Wales and Victoria in 1947 and 1948, and the submission by the Committee of reports in 1948 and 1949, the Commonwealth Parliament passed the *Snowy Mountains Hydro-electric Power Act* 1949 setting up an Authority to implement the proposals agreed upon.

The basis of the proposals was to impound the Snowy River waters at high elevations and, by diverting them into tunnels passing under the Alps, to use their potential power for the generation of electricity and then to discharge them into the Murray and Murrumbidgee River systems for use in the irrigation areas.

The scheme involves two main diversions, that of the Eucumbene, a tributary of the Snowy, to the Upper Tumut River, and that of the main stream of the Snowy River at Island Bend and Jindabyne to the Swampy Plain River. In addition, works required to make use of the waters of the Upper Murrumbidgee, the Upper Tumut, the Upper Tooma and the Geehi Rivers for power generation also provide additional regulation of these streams, and this makes more water available for irrigation. Details of the two trans-mountain diversions and the associated power works together with details of progress and construction are given in the chapter Electric Power Generation and Distribution.

An additional 500,000 acre feet of water per annum is now available for irrigation in the Murrumbidgee Valley. When all works are completed, it is estimated that the total gain to the Murrumbidgee by diversion and regulation will amount to 1,120,000 acre feet per annum and the total gain to the Murray will be 800,000 acre feet per annum. This additional water should be sufficient to provide irrigation for approximately 1,000 square miles of land, which is expected to result in a substantial increase in annual primary production.

International aspects

Australia maintains contact with international developments in water conservation and irrigation through its membership, since 1952, of the International Commission on Irrigation and Drainage. This Commission was set up in India in 1950 in order that the technical experience of all countries might be pooled for the benefit of all, and to promote the development and application of the science and technique of irrigation and drainage in the engineering, economic and social aspects. The Commission is constituted of National Committees of participating countries, and fifty-nine countries, including Australia, have so far been admitted to membership.

The Central Office of the International Commission is situated in New Delhi, India. Congresses, which are held every three years, have taken place in India, Algeria, the United States of America, Spain and Japan, in that order. The sixth Congress was held in India in January 1966.

An Australian National Committee was established following a meeting of representatives of Australian authorities held in Melbourne in 1953. At that meeting it was decided, *inter alia*, 'that a National Committee should be formed and that the National Committee would consist of representatives of Government Departments, Statutory Authorities, firms, and individuals actively interested in irrigation and drainage'. The Committee meets annually.

STATES AND TERRITORIES

The foregoing text deals with water conservation and irrigation in Australia generally and with international, national and interstate aspects. The following survey covers the local pattern of water resources and the steps taken by the State Governments to bring about their development. In the various States water policies tend to assume a distinctive and characteristic pattern closely allied with climatic conditions and specific local needs.

In Victoria almost every form of water scheme is in operation. In New South Wales major emphasis at present is on irrigation and stock development in the dry areas along the Murray and Murrumbidgee Rivers, though a substantial scheme of intensive irrigation is being conducted in the Murrumbidgee Irrigation Areas. In Queensland, up to the present, the predominant emphasis has fallen on water (mainly underground sources) for stock, and the development of small irrigation schemes in sub-humid and humid areas, especially to stabilise sugar production. Apart from regular irrigation practices along the Murray River, South Australian authorities are vitally concerned with reticulated supplies for rural areas and towns. Western Australia has developed unique rock catchments and piped supplies for agricultural areas and towns in dry districts. Tasmanian interest relates almost exclusively to hydro-electric generation. The Northern Territory is concerned primarily with stock supplies and the safeguarding of long stock routes.

* *See also* the chapter Electric Power Generation and Distribution. For more detailed information *see* special article by the then Commissioner, Snowy Mountains Hydro-electric Authority (Sir William Hudson) which appeared in Chapter XXIX. Miscellaneous of Year Book No. 42.

New South Wales

On page 1110 of Year Book No. 37 information is given on the pattern of rainfall and the history of irrigation in New South Wales. (*See also* the chapter Physical Geography and Climate of this issue.)

Administration

The Water Conservation and Irrigation Commission of New South Wales consists of three members appointed by the Governor. The operations of the Commission cover water conservation, control of irrigation areas, the establishment, operation and maintenance of works for domestic and stock water supply, irrigation districts, flood control districts, sub-soil drainage districts, constitution of water trusts, the issue of licences for private irrigation, artesian and shallow boring, assistance under the provisions of the farm water supplies scheme, and river improvement works.

Under the Water Act, 1912–1955 the right to the use and flow and the control of water in all rivers and lakes which flow through, or past, or are situated within, the land of two or more occupiers, is vested in the Commission for the benefit of the Crown. A system of licences operates for the protection of private works of water conservation, irrigation, water supply, drainage and prevention of inundation.

For particulars of the New South Wales–Queensland Border Rivers Agreement ratified by Acts of both States in 1947, *see* page 966 of this chapter.

Schemes summarised

The bulk of irrigated land is along the Murray and its tributary the Murrumbidgee. Smaller areas are served by the Wyangala Dam, Lake Cargelligo and Lake Brewster on the Lachlan (a tributary of the Murrumbidgee), by Glenbawn Dam on the Hunter River, by Keepit Dam on the Namoi River, by Burrendong Dam on the Macquarie River, and by the Menindee Lakes Storage on the Darling River. None of the other rivers is regulated by large head storages, though weirs and dams have been provided for town supplies, etc. in many places. A head storage on the Tumut River near Tumut is nearing completion. In addition, substantial use is made of artesian and sub-artesian water in pastoral areas.

New South Wales legislation provides for the constitution and control of various schemes having different characteristics and including irrigation areas, irrigation districts, water trust districts, flood control and irrigation districts, and river improvement districts. There are nine irrigation areas, although two of these, Yanco and Mirrool, are generally described under the one heading, namely, the Murrumbidgee Irrigation Areas. The Areas are: The Murrumbidgee Irrigation Areas, consisting of 451,263 acres served with water through a channel system stemming from the river at Berembed Weir; the Coomealla Irrigation Area of 34,626 acres, served by pumping from the Murray; the Curlwaa Irrigation Area of 10,393 acres, supplied from the Murray by pumping; the Hay Irrigation Area of 6,850 acres, supplied with water pumped from the Murrumbidgee; the Tullakool Irrigation Area of 18,006 acres, supplied from the Edward River by diversion at Stevens Weir; the Buronga (8,739 acres) and Mallee Cliffs (1,900 acres) Irrigation Areas, served by pumping from the Murray; and the Coleambally Irrigation Area (148,055 acres), served by diversion from the Murrumbidgee River. All these Areas are administered by the Commission, and details of the various schemes are given in the table on page 969.

The capacities of the main storages for irrigation in New South Wales (in acre feet) are:

Darling—Menindee Lakes Storages (2,000,000);

Murray—Half share of Hume Reservoir, weirs and locks to Wentworth (1,351,570); Stevens Weir, Edward River (7,165);

Macquarie—Burrendong Dam (964,000 irrigation storage; 397,000 flood mitigation storage);

Murrumbidgee—Burrinjuck Dam (837,000); Berembed Weir (10,000); Redbank Weir (7,360); Maude Weir (6,740);

Namoi—Keepit Dam (345,000);

Lachlan—Wyangala Dam (temporary reduced level 245,000); Lake Brewster (123,900); Lake Cargelligo (29,435); Jemalong Weir (2,200);

Hunter—Glenbawn Dam (185,000 acre feet irrigation storage; 108,000 acre feet flood mitigation storage); and

Snowy Mountains Hydro-electric Scheme—Lake Eucumbene (3,890,000); Blowering Dam (1,320,000); Jindabyne Reservoir (558,000); Tantangara Dam (206,000).

The total length of supply channels, drains, escape channels and pipe lines constructed by the Water Conservation and Irrigation Commission in New South Wales is 4,922 miles. This comprises 3,420 miles of supply channels (including main canals), 1,433 miles of drains and escape channels, and 69 miles of pipe lines.

Extent of systems and nature of irrigated culture

The following table shows the areas of the various irrigation systems and the areas irrigated in 1966–67 and corresponding particulars for the State as a whole during the seasons 1962–63 to 1966–67.

AREAS OF SYSTEMS AND OF LAND IRRIGATED: NEW SOUTH WALES 1962-63 TO 1966-67

(*Source:* Water Conservation and Irrigation Commission)

(Acres)

Season and system	Total area	Area irrigated(a)									
		Rice	Other cereals grown for grain	Fodder crops: Lucerne	Fodder crops: Other	Pastures	Vineyards	Orchards (b)	Vegetables	Fallow land and miscellaneous	Total
1966–67—											
Irrigation Areas—											
Murrumbidgee (within the Areas)	451,263	34,251	55,189	6,285	2,966	151,164	6,994	20,628	3,701	45,212	326,390
Lands adjacent supplied under agreement	n.a.	..	..	97	368	1,280	..	104	1	292	2,142
Coomealla	34,626	..	..	3	..	..	5,047	1,847	..	..	6,897
Curlwaa	10,393	..	..	32	..	128	379	1,317	..	..	1,856
Hay	6,850	..	538	..	..	2,420	..	..	..	..	(c)2,958
Tullakool	18,006	1,168	470	140	300	8,478	..	..	..	280	10,836
Buronga	8,739	..	..	..	..	..	252	544	..	..	796
Mallee Cliffs	1,900	..	..	57	..	..	149	155	..	..	361
Coleambally	148,055	13,650	31,371	1,252	1,055	29,607	51	72	204	16,870	94,132
Total, Areas	*(d)679,832*	*49,069*	*87,568*	*7,866*	*4,689*	*193,077*	*12,872*	*24,667*	*3,906*	*62,654*	*446,368*
Irrigation Districts—											
Benerembah	112,818	6,319	13,595	1,457	1,697	36,867	..	..	213	12,328	72,476
Tabbita	32,330	418	1,898	860	63	3,815	..	..	12	1,720	8,786
Wah Wah	579,132	..	6,489	2,183	849	10,950	..	..	..	6,458	26,929
Berriquin	804,057	..	29,619	20,554	2,489	252,007	..	..	437	13,364	318,470
Wakool	503,322	8,812	7,675	1,834	3,225	83,246	..	..	12	2,856	107,660
Denimein	147,005	3,380	3,329	1,275	473	24,040	..	5	24	778	33,304
Jemalong and Wylde's Plains	224,556	..	3,405	8,820	445	11,595	..	..	80	1,050	25,395
Gumly	353	..	35	39	..	28	..	20	37	..	159
Deniboota	338,054	5,641	5,912	3,192	1,632	48,046	..	..	12	4,828	69,263
Total, Districts	*2,741,627*	*24,570*	*71,957*	*40,214*	*10,873*	*470,594*	..	*25*	*827*	*43,382*	*662,442*
Flood control Districts—											
Lowbidgee	399,707	..	..	..	..	..	..	..	..	..	n.a.
Medgum	272,800	..	..	..	..	..	..	..	..	..	n.a.
Total, Flood Districts	*672,507*	..	..	..	..	..	..	..	..	..	*n.a.*
Irrigation Trusts—											
Pomona	1,580	..	..	..	..	..	760	130	..	..	890
Goodnight	1,104	..	..	..	..	..	619	43	..	..	662
Bungunyah–Koraleigh	1,810	..	..	..	..	..	920	113	160	..	1,193
Glenview	661	..	..	..	..	341	..	..	..	..	341
Bringan	4,933	..	..	..	..	..	..	..	..	..	n.a.
Bama	3,446	..	..	..	..	..	..	..	..	..	n.a.
West Cadell	5,827	..	..	..	..	..	..	..	..	..	n.a.
Total, Trusts	*19,361*	..	..	..	..	*(d)341*	*(d)2,299*	*(d)286*	*(d)160*	..	*(d)3,086*
Water Trusts— Domestic and stock supplies	2,829,791	..	..	..	..	..	..	..	..	..	..
Licensed diversions	n.a.	..	32,687	58,797	33,258	154,904	2,764	10,584	11,746	24,145	328,885
Total, 1966-67	**6,943,118**	**73,639**	**192,212**	**106,877**	**48,820**	**818,916**	**17,935**	**35,562**	**16,639**	**130,181**	**1,440,781**
1965–66	6,928,808	64,341	164,059	101,901	50,417	742,249	16,361	36,065	16,593	116,453	1,308,439
1964–65	6,912,735	61,617	132,624	42,901	9,491	552,888	14,035	27,605	4,375	81,494	(e)1,198,404
1963–64	6,912,942	59,331	82,376	45,823	11,846	505,176	12,810	24,451	2,859	82,046	(e)1,060,479
1962–63	6,972,239	53,578	85,459	42,814	18,296	520,167	13,086	21,559	4,033	72,179	(e)1,036,846

(*a*) Excludes Flood Control Districts and some Irrigation Trusts, particulars for which are not available. (*b*) Citrus and deciduous; in 1966–67 deciduous amounted to 13,285 acres, of which 10,636 acres were in the Murrumbidgee Irrigation Areas. (*c*) Includes lands outside irrigation areas supplied under special agreement. (*d*) Incomplete. (*e*) Includes total area irrigated by Licensed Diversions, but details for individual crops, etc., are not available.

Irrigation Areas

Murrumbidgee. These areas, together with adjacent lands supplied under agreement, received 496,290 acre feet, or nearly a fifth of the total water (2,688,105 acre feet) allocated within the State for stock, domestic supply and irrigation. They are served by the Burrinjuck Dam on the Murrumbidgee, forty miles north-west of Canberra. The catchment above the dam is about 5,000 square miles. The river rises on the high plateau north of Mount Kosciusko where the average annual rainfall exceeds 60 inches. Flow for the irrigation areas and districts is supplemented by unregulated flow from the Tumut River below the dam. The dam also provides town supplies for Gundagai, Wagga, Narrandera, Hay, Balranald, and for towns served by the South-West Tablelands scheme.

Domestic and stock water and water for irrigation are supplied to the Irrigation Districts of Tabbita, Benerembah and Wah Wah, and the Flood Control and Irrigation District of Lowbidgee. Flood flows are relied on to serve the Lowbidgee district, and water is not released from the dam for that purpose. For the other undertakings, however, water is stored during the winter, fed by melting snows and spring freshets, and is released during the September–May irrigation season. It passes along the river channel to Berembed Weir, 240 miles westward, where it is diverted to the main canal with an off-take capacity of 1,600 cubic feet a second. The main canal has been completed to beyond Griffith, 106 miles from the off-take. Reticulation channels aggregate approximately 900 miles and drainage channels 880 miles. In addition, approximately 440 miles of supply channels run through irrigation districts adjacent to the Murrumbidgee Areas in which the water supply is operated and maintained by the Water Conservation and Irrigation Commission.

The Water Conservation and Irrigation Commission controls land transactions and water supplies for the Murrumbidgee Irrigation Areas only, and has no jurisdiction over land transactions in the adjacent irrigation districts, although it is responsible for the operation and maintenance of the water supply in these areas. Other local government services, including electricity and town water supply, are provided by Councils. Land is disposed of by the Commission by purchase or under perpetual lease tenure or leased for short terms for grazing or cultivation. The area under occupation at 30 June 1967 was 414,576 acres, including 37,925 acres held for short lease grazing, agriculture, etc.

The land on which the Murrumbidgee Irrigation Areas and associated districts are situated originally comprised large sheep stations and was sparsely populated, but at 30 June 1967 its population was approximately 30,000, that of Leeton Shire being 11,040 and that of Wade Shire, 18,090. The principal products of the Murrumbidgee Irrigation Areas are wool, livestock for slaughtering, rice, citrus fruits, peaches and nectarines, grapes, tomatoes, peas, beans, and root vegetables. Rice growing was initiated on the Areas in 1924 and has since become the most important crop. In a normal season the water supplied for rice represents about half the total delivered to the Areas.

Other Irrigation Areas. The Coomealla, Tullakool, Buronga, Mallee Cliffs, Hay, Curlwaa, and Coleambally Irrigation Areas follow the same administrative pattern as the Murrumbidgee Areas—that is, land transactions are administered by the Water Conservation and Irrigation Commission which is responsible also for the operation and maintenance of works to supply water.

Irrigation Districts

These districts are set up under the Water Act, 1912–1955 for (*a*) domestic and stock water supply and (*b*) irrigation. They differ from water trusts in that the cost of the works is not required to be repaid over a period, but annual charges are made by the State for water supplied to landholders.

Since the completion of the Hume Reservoir, several such districts have been established along the Murray to utilise the New South Wales share of the storage. Water is not available for the whole of the 5,000,000 acres adjacent to the Murray in New South Wales, and therefore the schemes are based on 'extensive' irrigation, that is, water rights are allotted to holdings on the basis that only a portion of each holding (one acre in three, five or ten, according to the district, etc.) will be irrigated, but additional water, when available, may be obtained by landholders. 'Water right' means right to such a quantity annually of water, 12 inches deep, as will cover an area of one acre.

Water to serve Berriquin, Deniboota and Denimein Districts is diverted through a main canal which is approximately 100 miles long. Water for the Wakool Irrigation District and the Tullakool Irrigation Area is diverted from the Edward River at Stevens Weir, and a supplementary supply is also obtainable from Mulwala canal. At 30 June 1967 the total length of completed canals and channels in Berriquin District was 1,000 miles, comprising Mulwala canal 75 miles, Berrigan channel 22 miles, subsidiary channels 788 miles, escape channels 105 miles, and cross drainage channels 10 miles. Off-take capacity of the Mulwala canal is 5,000 acre feet a day. Wakool, with 422 miles of channel, contains 318 holdings, and the area developed by irrigation includes about one acre in six of the total area. Sheep raising and rice growing are the main industries. Considerable subdivision has occurred within the Berriquin District, and the proportion of the total area developed for irrigation is higher than in the case of Wakool. Sheep (including fat lambs), dairying, wheat, and rice growing are the main industries.

Water Trust Districts, Irrigation Trusts and Flood Control and Irrigation Districts

The Water Act, 1912–1966 provides for the constitution of Trust Districts for domestic and stock water and irrigation, and empowers the Commission to construct, acquire or utilise necessary works. When the works are completed, they are handed over to trustees to administer. The trustees are elected by the occupiers of the land and act with a representative of the Commission. They are empowered to levy and collect rates covering the cost of the works repayable to the Crown by instalments and also the cost of operation and maintenance of the works. The rates are struck according to the area of land which benefits. The following are the water trusts, other than irrigation, as at present constituted (the area in acres of each district being shown in parenthesis): *Murray River*—Little Merran Creek (157,440), Bullatale Creek (68,320), Poon Boon (34,300), Minnie Bend Flood Prevention (2,190); *Murrumbidgee River*—Yanco, Colombo and Billabong Creeks (1,007,780); *Lachlan River*—Marrowie Creek (292,640), Torriganny, Muggabah and Merrimajeel Creeks (170,240), Ulonga (64,960), Micabil Weir (11,500), Condobolin West Weir (4,480); *Miscellaneous*—Great Anabranch of Darling River (959,184), Nidgery Weir (46,880), Algudgerie Creek (9,760), Collarenebri town water supply (117)—making in all a total area of 2,829,791 acres. Twelve of these trusts have been formed for the provision of water for domestic and stock purposes, one for a town supply and one for flood prevention.

Irrigation Trusts are established under the same Act and are administered by trustees in a similar way. There are seven of these trusts.

The Lowbidgee Provisional Flood Control and Irrigation District, the first of its kind, was constituted in 1945. Its purpose is to provide flood irrigation for pasture lands on the lower Murrumbidgee by water diverted from the Maude and Redbank Weirs. Another district, Medgun, near Moree in the north-west, is also in operation.

River, lake and farm water supplies

During recent years the numbers of licences and permits issued to individuals to draw water from rivers and lakes for irrigation have increased substantially, especially along the coastal streams in sub-humid districts where the value of supplementary irrigation is becoming more recognised as a means of stabilising production in dry months. There has also been a considerable increase along the Murrumbidgee, Lachlan, Namoi, and Macquarie Rivers.

Under the Farm Water Supplies Act, 1946, technical advice and assistance, and also financial assistance, are made available to help individual farmers and groups of farmers to provide and improve water supplies for domestic, stock and irrigation purposes by means of wells, bores, excavated tanks, weirs or dams, and flood and spray irrigation systems.

Underground water

Extensive use is made of artesian, sub-artesian, and shallow underground water. The Great Artesian Basin underlies an area of some 81,250 square miles in north-western New South Wales. Eighty-seven Bore Water Trusts and twelve Artesian Wells Districts have been constituted. Bore Trusts are administered in the same way as Water Trusts, but in Artesian Wells Districts the settlers maintain the drains. Bore Trusts and Artesian Districts cover 5,500,000 acres and distribute water through 3,592 miles of open earth drains. At 30 June 1967, 1,167 artesian bores had been constructed in the New South Wales section of the Basin. At that date 692 bores were flowing and were capable of producing about 63,898,000 gallons a day. Conservation measures control this to about 51,600,000 gallons a day. The total length of bore drains, including those for Trusts and Districts, is approximately 8,000 miles.

Of other structural basins of sedimentary rocks, e.g. Murray, Sydney, Oxley, and Clarence Basins, the Murray is the largest and also the most important in that it affords stock water supplies over an extensive area of the south-western section of the State. Only a few of these bores flow, the remainder being sub-artesian. Good supplies for stock and, in some instances, small scale irrigation, are obtained from porous sandstone in the Moss Vale-Picton area, but the remainder has limited potential. Stock supplies are obtained from bores in the fringe zones of the Oxley Basin, but the centre of this basin lies under the Liverpool range. The Clarence Basin is relatively unimportant from a groundwater viewpoint, but stock supplies are obtained from some sections.

In other parts of the State the largest and best quality groundwater supplies are obtained from sands and gravels in the alluvium of the major rivers and their tributaries, particularly the western-flowing rivers, e.g. Lachlan, Macquarie and Namoi. Supplies ranging from 10,000 to 210,000 gallons an hour are obtained from wells and bores in these areas and are used for irrigation and town water supply. The Government is carrying out investigations to determine the ground-water potential of the alluvium of such valleys, particularly with regard to irrigation use, and a test-boring programme is in progress in the Lachlan and Namoi Valleys. Investigation programmes have also been initiated in the

coastal river systems, commencing with the Hastings and Bega river valleys, but the groundwater potential of the coastal valleys is quite limited compared with the inland drainage systems. Old sand dune areas along the coast provide large supplies of good quality water. However, since the soils of these areas are not suited to agricultural pursuits, exploitation has been largely confined to the Sydney and Newcastle areas. Initially a source of Sydney's water supply, the Botany sands are now utilised mainly by industry. The Tomago sands provide a considerable proportion of the Newcastle water supply.

The older rocks, which are mostly folded and jointed, are very variable in their groundwater potential and only rarely do they yield supplies sufficient and suitable for limited irrigation. Where suitable conditions obtain, they yield useful stock supplies, mostly at depths between 50 and 250 feet.

A licence under the Water Act, 1912–1966 is required for all bores sunk in any part of New South Wales, and details of over 30,000 bores and wells in the State are recorded. When assessed in relation to the geologic and topographic conditions of any particular area, such records provide valuable evidence of the groundwater potential and are thus of considerable benefit to landholders.

Future programme

The programme of development in hand includes the provision of additional dams and storages, weirs, and flood mitigation and river protection works in various parts of the State. Work has commenced on a dam at Pindari on the Severn River, and legislation has been passed authorising the construction of a flood control and irrigation dam at Warkworth in the Hunter Valley. The Hunter River development, of which Glenbawn Dam is an integral part, concerns an exceptionally fertile coastal valley, forming the hinterland to Newcastle, where the annual rainfall is not heavy and variations from month to month are considerable. This is the first coastal scheme initiated in New South Wales. At Wyangala Dam, on the Lachlan River, the strengthening and enlargement of the original dam is nearing completion. The new storage capacity of 560,000 acre feet will be increased to 1,000,000 acre feet by 1970 following the installation of radial gates in the new spillway. Construction of the Blowering Dam on the Tumut River was completed in 1968. Within the new Coleambally Irrigation Area further development of farms has been carried out and water is being supplied by the new diversion weir at Gogeldrie. At 30 June 1967, 194 large area farms and 15 horticultural farms had been allotted.

Victoria

Particulars of the rainfall pattern of Victoria were given on page 1117 of Year Book No. 37. (*See also* the chapter Physical Geography and Climate of this issue.)

Administration

Victorian Governments have been active in the development of country water supplies since the 1860's when major works to supply the Bendigo goldfields were undertaken. Local trusts to construct and operate waterworks under Government supervision were provided for in the *Water Conservation Act* 1881. Development under the trust system was greatly stimulated by the *Irrigation Act* 1886, which provided for the construction of national headworks by the State, and vested in the Crown the right to the use and control of all surface waters. By 1900 there were 33 irrigation trusts and 18 other rural water supply trusts, but the system of local control was then breaking down under financial difficulties.

The *Water Act* 1905 established the State Rivers and Water Supply Commission to take over the Irrigation Trust districts (except the still-existing First Mildura Irrigation Trust) and to exercise the State's functions in the further control and development of surface waters outside the metropolis. The Commission now supervises all private diversions from streams and directly administers irrigation districts covering 2,253,000 acres, rural waterworks districts covering 8,001,000 acres, drainage and flood protection districts covering 149,000 acres, and urban water supplies serving 215,000 people. It also supervises the activities of local urban water supply authorities supplying 616,000 people in 238 towns, as well as 86 local sewerage authorities and 29 river improvement and drainage authorities.

Works summarised

Since the State Rivers and Water Supply Commission began its operations in 1906 the capacity of storages under its control has been increased from 172,000 acre feet to 4,658,920 acre feet. In addition, Victoria has in effect a half share in River Murray Commission storages totalling 2,703,150 acre feet, bringing total capacity available to Victoria at 30 June 1967, to 6,010,490 acre feet. Most of the water used from these storages is for irrigation. The area irrigated has increased from 105,000 acres in 1906 to 1,313,888 acres in 1966–67. Irrigation deliveries in 1966-67 totalled 2,130,053 acre

feet. The value of irrigation production in 1965–66 was estimated at $159,550,000. Of the total irrigation production about one-quarter was from lands irrigated by 'private diverters', i.e. irrigators who are authorised to take water from streams, lakes, etc., but who do not come within the boundaries of an irrigation district.

Storages

Capacities of principal storages (in acre feet) and system totals at 30 June 1967 were as follows:
Goulburn System—Eildon, 2,750,000; Waranga, 333,400; total, 3,130,650;
Murray System—half share of Murray storages, 1,351,570; total, 1,392,430;
Ovens System—Lake Buffalo, 19,500; total, 19,500;
Loddon System—Cairn Curran, 120,600; Tullaroop, 60,000; Kerang Lakes, 57,700; total, 276,250;
Campaspe–Coliban System—Eppalock, 252,860; Coliban storages, 63,830; total, 316,690;
Wimmera–Mallee Systems—Rocklands, 272,000; Toolondo, 86,000; Bellfield, 63,680; total, 627,890;
Maffra–Sale System—Glenmaggie, 154,300; total, 154,340;
Werribee–Bacchus Marsh—total, 34,900;
Mornington Peninsula—total, 17,640.

Nature of irrigated culture

The following table shows the areas irrigated in the various irrigation systems in 1966–67, and corresponding particulars for the State as a whole during the seasons 1962–63 to 1966–67.

AREA OF LAND IRRIGATED: VICTORIA, 1962-63 TO 1966-67

(*Source:* State Rivers and Water Supply Commission)

(Acres)

Season and system	Cereals	Fodder crops: Lucerne	Fodder crops: Other	Pastures: Native	Pastures: Sown: Annual	Pastures: Sown: Perennial	Vineyards	Orchards	Market gardens	Fallow and miscellaneous	Total
1966–67—											
Goulburn-Campaspe-Loddon	17,145	24,692	6,238	22,897	257,978	201,026	355	24,970	5,711	20,801	581,633
Murray—											
Torrumbarry	6,175	5,690	6,409	20,672	140,548	88,427	4,250	1,568	717	3,858	278,314
Murray Valley Irrigation Area	59	6,840	2,251	657	62,506	45,154	116	6,591	454	333	124,961
Pumping(*a*)	123	850	191	311	103	201	38,982	3,279	157	1,402	45,599
Total, Murray	*6,357*	*13,380*	*8,851*	*21,640*	*203,157*	*133,782*	*43,348*	*11,438*	*1,328*	*5,593*	*448,874*
Other northern systems	47	1,144	..	807	1,751	11,026	..	3,196	496	38	18,505
Southern systems	55	1,340	138	2,835	1,358	62,990	..	638	5,994	312	75,660
Private diversions(*b*)	1,001	9,312	3,247	6,534	16,390	120,725	3,715	6,352	13,088	8,852	189,216
Total, 1966-67	**24,605**	**49,868**	**18,474**	**54,713**	**480,454**	**529,549**	**47,418**	**46,594**	**26,617**	**35,596**	**1,313,888**
1965–66	29,347	48,016	19,123	54,967	472,426	494,040	45,697	44,851	27,653	26,541	1,262,661
1964–65	8,048	42,320	14,116	51,210	443,227	484,634	47,778	44,743	26,884	26,095	1,189,055
1963–64	14,878	42,878	21,031	41,360	427,160	453,986	45,257	43,891	24,422	22,378	1,137,241
1962–63	26,113	43,180	22,820	61,317	418,025	440,360	45,757	43,059	22,634	28,290	1,151,555

(*a*) Includes First Mildura Irrigation Trust. (*b*) Excludes private diverters in the Torrumbarry System, but includes all other private diverters along the Murray River.

Irrigation systems

Goulburn–Campaspe–Loddon. The principal storage for Goulburn waters is Lake Eildon, which was completed in 1956, submerging the original 306,000 acre feet Eildon storage completed in 1927. For the distribution of additional supplies available from Eildon and from other new storages on the Loddon and Campaspe rivers it has been necessary to undertake major enlargements in the distribution system by a long-term programme of channel works which is still in progress. Deliveries have increased from 395,000 acre feet in 1954–55 to 909,000 in 1966–67. Goulburn River water is diverted to the irrigation areas by gravitation from the pool formed by the Goulburn Weir, near Nagambie, completed in 1890 as a State work. The East Goulburn main channel of 1,000 cusecs capacity supplies the areas around Shepparton. Two 1,500 cusec channels to the west convey water to the off-river Waranga Reservoir and supply part of the Rodney area through off-takes on the way. From Waranga Reservoir there are two main outlets, one supplying the western part of the Rodney area and the other, of 1,200 cusecs capacity, supplying the Waranga Western Main Channel, which runs more than 100 miles west across the Campaspe and Loddon Valleys to Boort.

Flows in the Waranga Western Main Channel are augmented by the injection of Campaspe water through a pumping station of 200 cusecs capacity near Rochester. Supply to the Tragowel and Boort areas is augmented by gravitational diversion of Loddon water.

The gross area of holdings in the Goulburn–Campaspe–Loddon systems is 1,351,862 acres. The main products are dairy produce, fruit, wool, and fat lambs. Annual production of deciduous canning fruits in the eastern part of the system is about two-thirds of Australia's total.

Murray River system. Water is diverted from the Murray by gravity at the Yarrawonga Weir for the Murray Valley Irrigation Area and at the Torrumbarry Weir for the Torrumbarry irrigation system which extends to Swan Hill. Holdings in the Murray Valley area total 301,749 acres, devoted mainly to dairying, fat lambs and canning fruit. Holdings in the Torrumbarry system total 372,342 acres, devoted mainly to dairying and the production of fat lambs, with a concentration of vineyards, orchards and market gardens around Swan Hill.

Downstream from Swan Hill there are 5 districts supplied by pumping: the district of the First Mildura Irrigation Trust and the 4 Commission districts of Nyah, Robinvale, Red Cliffs, and Merbein. These districts together serve 80,615 acres, producing mainly dried vine fruits, with some citrus fruits and table and wine grapes.

Southern systems. The Macalister district, covering 129,939 acres around Maffra and Sale, is supplied from the Macalister River, regulated by Lake Glenmaggie, and from the unregulated flow of the Thomson River. Dairy farming is the principal activity. The Bacchus Marsh and Werribee Districts, supplied from storages in the Werribee River only 20 miles west of Melbourne, cover 16,341 acres intensively developed for dairying and vegetables.

Wimmera-Mallee domestic and stock supply system

Storages in the Grampians in south-west Victoria ensure farm water supplies over an area of 11,000 square miles extending northward through riverless pastoral and cereal lands to the Murray. Farm dams throughout this region, which covers one-eighth of the total area of the State, are filled once each year, in the winter-spring season, through the medium of 6,600 miles of Commission channels and about 4,000 miles of private channels. Without this supply, occupation of the region would be extremely hazardous. Headworks storage capacity has now been increased from 564,210 acre feet to 627,890 acre feet by construction of Lake Bellfield. Fifty towns, with a population of 46,000, receive their supply from the same system. Near Horsham and Murtoa, close to headworks in the south, a supply is maintained for the irrigation of an area of 7,500 acres, mainly for dairying.

Drainage, flood protection and river improvement

The largest work in this category undertaken by the State Rivers and Water Supply Commission is the Koo-wee-rup–Cardinia flood protection district embracing 89,245 acres of a continuous depression along the seaboard of Westernport. Once useless, indeed a hindrance to communication, this area now yields primary products worth several million dollars each year.

By the *River Improvement Act* 1948, the formation of local river improvement and drainage trusts under the supervision of the Commission has been greatly facilitated and, since 1950, 28 such trusts have been formed. The importance of river improvement work is expected to continue to grow.

In 1963 the Dandenong Valley Authority was created, by special legislation, with jurisdiction over the whole catchment of the Dandenong Creek (300 square miles) for purposes of arterial drainage, river improvement and flood protection. In June 1966 the Authority took over the Commission's Carrum Drainage District.

Finance

The net capital liability of the Commission at 30 June 1967 for works under its direct control was $277 million. Of this amount, $182 million was expended for irrigation and $24 million for rural, domestic and stock supplies, the cost being borne entirely by the State. The total liability for urban supplies was $51 million, of which $27 million was borne by the districts concerned. The remaining $20 million was for expenditure on flood protection and drainage ($3 million), and items such as loan flotation expenses, miscellaneous surveys and investigations, and buildings, plant and stores.

Underground resources

Underground water. The investigation, exploration and survey of underground water resources in Victoria is carried out jointly by the State Rivers and Water Supply Commission and the Department of Mines. The Commission is concerned mainly with investigation of shallow waters in irrigation districts, while the Department covers all other work, including exploratory drilling to 5,500 feet.

Underground water is the only available source of supply other than rain in some areas of the State. It is of particular importance in the western portions of the Wimmera-Mallee districts where annual rainfall ranges between 10 and 20 inches and there are no surface streams. Elsewhere underground water is used to supplement surface supplies and in places it may be the only developed source for town, industry, rural, domestic, stock, or irrigation use.

The Wimmera and Mallee districts are situated over part of the Murray Basin where, to the west of the Wimmera River, Miocene marine limestones form an aquifer with water suitable for town supply and irrigation. It is used for this purpose at Kaniva, Murrayville and Nhill, where yields between 10,000 and 60,000 gallons per hour may be obtained. North of Murrayville and Underbool the water in the limestones is more saline and in the extreme north it is too saline even for stock use. East of the Wimmera River to Lake Tyrrell and north of Swan Hill the marine rocks consist of marls and silts with calcareous beds capable of yielding saline water at less than 1,000 gallons per hour. These aquifers are not developed. Lower Tertiary swamp, deltaic and estuarine carbonaceous and ligneous sediments underlie and extend eastward of the marine rocks. Sands in these sediments contain water of greater or lesser salinity than that of the marine deposits. Yields of up to 10,000 gallons per hour have been obtained from the deltaic aquifers between Swan Hill and Robinvale. In the Natya-Kenley area the water is suitable for most stock purposes and for limited irrigation under favourable conditions. Overlying the marine and estuarine sediments there are aquifers consisting of Pliocene to Pleistocene terrestrial, fluviatile and lacustrine sands and sandstones. Yields from these rocks are limited to windmill supplies. The quality is variable and in the north-west highly saline. East of the Avoca River the deposits of the Murray Basin are entirely non-marine and consist of terrestrial, fluviatile and lacustrine gravels, sands, silts, and clays to a maximum depth of about 600 feet. Water from the sands and gravels is of variable quality. In places it is too saline for stock use, but the quality improves towards the east and it is used for town supply at Katunga and Wangaratta, and at Barnawartha, Bright and Chiltern where the deposits partly fill valleys in the bedrock of the highlands.

In the Otway Basin in the south-west of Victoria the Upper Cretaceous-Lower Tertiary sands have been developed for underground water supplies to Portland, Heywood, Port Fairy, Peterborough, Port Campbell, and Timboon. In the central (Warrnambool and Koroit) and northern parts of the basin the waters are suitable only for stock. In the areas of better quality water the depth of the aquifers (2,000–4,500 feet) renders their development uneconomic except for town supply and industry. Oligocene to Miocene marine limestones occur in the south-central and western portions of the basin. The salinity of the water in the limestones is often less than that of the water in the sands beneath, but the limestone waters are generally hard. They are used in part to supply Portland and also for irrigation. Small underground water supplies are obtained from the Pliocene-Pleistocene deposits of ferruginous sands, marine sandy limestones and dune limestones in the west and from the dune limestones along the coast between Warrnambool and Portland.

In and around the structural depressions of the Port Phillip and Westernport Bay districts there are several small areas where underground water of good quality occurs. Among these are the Lower Tertiary sand aquifers at Anglesea which are being developed to yield approximately 200,000 gallons per hour for industrial purposes; the Middle Miocene sands, shelly silts and limestones which have been developed for market garden watering south-east of Melbourne; and the Pleistocene sands and shelly silts on the Nepean Peninsula where the water is used for market gardens and pasture irrigation.

Irrigation. Brackish waters in the Eocene to Oligocene sands under the Werribee Plains have some potential for industrial use. The Westernport area has yielded large supplies of water from Tertiary marine and non-marine sands, and from fractured fresh basalt in some areas. Extensive use is made of water from the sands for irrigation of pastures and cash crops in the Koo-wee-rup Swamp area. Yields of up to 30,000 gallons per hour are common. In the Lang Lang area the water is used for town and industrial supply, but not as yet for irrigation. Stock supplies with one or two minor exceptions are available at shallow depth over the whole of the area.

The Gippsland Basin contains two main groups of water-bearing rocks, the Lower Tertiary coal measures and marine sands, and the Upper Tertiary sands and gravels. Water from the Lower Tertiary rocks is frequently high in bicarbonate and therefore soft. It is used for irrigation at Bairnsdale and Yarram, and some abnormally hot water is used for industrial purposes at Maryvale. The Upper Tertiary rocks yield large quantities of very good quality water, mainly in the east-central part of the basin, where it is used extensively for irrigation. Stock supplies are generally available at shallow depth in rocks of various types and ages.

The pre-Upper Cretaceous sedimentary and igneous rocks of the highland areas generally yield small supplies of water suitable for stock. Exceptions to this are the Devonian sandstones of the Grampians where large supplies of good quality water may be obtained, and the better quality waters suitable for domestic use from the higher rainfall area of the eastern highlands of the State.

The Lower Tertiary volcanic rocks, mainly basalts, yield large supplies, up to 15,000 gallons per hour where the basalt is well jointed and little weathered, but only small quantities where the rocks are weathered. Where yields are large as in the west and south-west of Gippsland and on French Island the water quality generally is suitable for irrigation, but on the Bellarine and Mornington Peninsulas, Phillip Island and at Cranbourne the small yields of water are suitable for limited stock use only. Pliocene to Pleistocene volcanic rocks, basalts with tuffs and agglomerate occur extensively over the Werribee Plains and Western District and in valleys in the western half of the Central Highlands. Yields from these rocks are variable, the maximum recorded being 16,000 gallons per hour. From the weathered basalt yields are usually less than 1,000 gallons per hour. The quality is generally suitable only for stock but may be suitable for irrigation. Underground water derived from the later basalts of the stony rises west of Colac usually has high nitrate content.

Future programme

In July 1963 the Government announced plans for a long-term storage programme for irrigation purposes to cost a total of $75 million between 1963–64 and 1973–74. Three of these storages, namely Chowilla Reservoir (a River Murray Commission Storage), Lake Buffalo (second stage) and Lake Mokoan, appear in the list of dams and reservoirs projected in the table on page 961.

Since the long-term storage programme came into operation, new storages have been completed for the Wimmera–Mallee System (Lake Bellfield, near Horsham); the Mornington Peninsula System (Devilbend Reservoir and Tarago Reservoir); the Goulburn-Murray System (Corop Lakes) and private diverters near Benalla (Lake Nillahcootie); and along the Buffalo River (Lake Buffalo, first stage).

At present work is proceeding on new storages to supplement supply to the Bacchus Marsh–Werribee System (Lake Merriane) and the Goulburn–Murray System (Lake Mokoan, near Benalla).

Works expenditure of about $4,000,000 per year is carried out from about thirty-five operating centres throughout the State. In addition, four major construction centres have been spending about $2,500,000 annually for many years on a programme of channel and drainage works in the Goulburn–Murray System, and the end of this programme is not yet in sight.

A major new development has been a grant of $3,600,000 from the Commonwealth Government to finance a scheme to reduce the flow of saline drainage water into the River Murray.

Queensland

Particulars of the rainfall pattern of Queensland are given in Year Book No. 37, page 1122. (*See also* the chapter Physical Geography and Climate of this issue.)

Administration

In Queensland the right to the use and flow of non-tidal surface water contained in, or flowing through or past, the land of two or more occupiers, and all artesian and sub-artesian water vests in the Crown. Subject to certain reservations for local authority and other purposes, such water is controlled by a Commissioner of Irrigation and Water Supply. Private diversions from watercourses, artesian wells and, in certain declared areas, sub-artesian wells, are subject to licence by the Commissioner. Dams and weirs are constructed by the Commissioner to safeguard supplies in streams from which private pumping for irrigation takes place, and also to provide water for irrigation areas established by the Commissioner. For a description of the development of the present administration *see* Year Book No. 42 and earlier issues.

Irrigation—extent, systems and methods

Queensland sugar cane represents in value about 40 per cent of the agricultural production of the State. In 1966–67 almost 23 per cent of the sugar cane acreage was irrigated, representing 41 per cent of the total area irrigated in the State. Tobacco is another major crop, and the area irrigated during 1966–67 represented 97 per cent of the total plantings.

Most irrigation in Queensland is undertaken by farmers operating under licence to obtain water by pumping from streams or from natural underground storages. Over half the total area irrigated in Queensland is supplied from underground water. The main areas where these supplies have been developed extensively are the Burdekin Delta (Ayr-Home Hill area), the Pioneer Valley, Callide Valley, Lower Burnett (Bundaberg area), Lockyer Valley, and Redland Bay.

Furrow irrigation is used for cotton, sugar cane, some tobacco, and miscellaneous row crops. Spray irrigation is used widely on fruit, vegetables, fodder crops, sugar cane, and the major part of the tobacco crop. Irrigation is required around-the-year for most of Queensland, as the timing and duration of the summer 'wet' season are too variable to enable a definite non-irrigation season to be fixed, as can be done in southern States.

AREA OF LAND IRRIGATED: QUEENSLAND, 1962-63 TO 1966-67

Season and division	No. of irrigators	Area irrigated (acres)							
		Vegetables	Fruit and vineyards	Sugar cane	Tobacco	Cotton	Other crops	Pastures	Total
1966-67—									
Southern Queensland	6,598	32,849	7,560	45,542	2,118	5,026	67,484	28,618	189,197
Central Queensland	679	1,013	505	252	56	2,889	16,396	2,961	24,072
Northern Queensland	2,327	5,336	975	96,827	9,606	82	4,629	13,329	130,784
Total, 1966-67	**9,604**	**39,198**	**9,040**	**142,620**	**11,781**	**7,997**	**88,508**	**44,908**	**344,052**
1965-66	9,897	38,726	9,049	140,994	12,116	6,333	90,070	35,246	332,534
1964-65	9,310	35,020	8,092	120,556	13,499	4,148	71,634	28,224	281,173
1963-64	8,930	36,329	7,315	98,204	15,079	2,717	65,078	27,360	252,082
1962-63	8,562	34,258	7,020	81,506	15,801	2,206	58,029	22,341	221,161

Areas under private irrigation

In five important areas irrigation has been developed by private pumping. In the Lockyer Valley, thirty miles west of Brisbane, more than a third of an estimated total irrigable area of 60,000 acres is under irrigation. The valley comprises an extensive flood plain where heavy black alluvial soil thickly overlies gravels and sands carrying water suitable for irrigation, which is necessary for continuous agricultural production. A number of small weirs with a total storage of 1,340 acre feet have been constructed on Lockyer Creek by the Irrigation and Water Supply Commission; these also tend to augment and conserve underground supplies. Approval has recently been given for the construction of an off-stream storage in the Atkinson's Lagoon area which will be supplied by diversion from Buaraba Creek and several adjoining catchments. The storage will provide a regulated supply of water in Buaraba Creek and along the lower end of Lockyer Creek. The Lockyer Valley produces a substantial proportion of Queensland's onions, potatoes, pumpkins, lucerne, hay, green fodder, maize, and dairy products.

The Callide Valley in central Queensland is an important source of grain, dairy products, fodder, and cotton and is largely dependent on irrigation from underground water resources. Some 10,000 acres are now irrigated from underground supplies. The broad expanses of alluvium in the Pioneer Valley near Mackay have been extensively developed for cane production. The area under irrigation from groundwater and surface supplies is some 12,000 acres. The lands in the vicinity of Bundaberg are cultivated for sugar cane production and over 40,000 acres are irrigated from surface and underground supplies.

The other important area is the fertile delta region of the Burdekin River, where the irrigated area is over 67,000 acres. The delta has ground water supplies at shallow depth, and these have been tapped to obtain supplies in the dry periods of the year. Sugar is the main crop irrigated, together with citrus fruits, pineapples, vegetables, and tobacco. In 1940 the Burdekin River Trust was formed to safeguard the sugar areas of the delta from erosion and floods, and an irrigation research station studies the development of pastures and crops. A scheme to replenish the subterranean water supplies in the North Burdekin Delta by pumping from the Burdekin River is in operation under the control of the North Burdekin Water Board. There is a similar Board in operation in the South Burdekin Delta.

Government irrigation areas and projects

The Irrigation and Water Supply Commission has constructed and operates five dams and forty-four weirs with a storage capacity of 568,121 acre feet. Water from these storages supplies the following four irrigation areas operated by the Commission and supplements numerous streams from which pumping for private irrigation takes place.

Mareeba-Dimbulah Irrigation Area. In 1952 an irrigation undertaking was established to assist tobacco production in the valleys of the Walsh and Barron Rivers. Tinaroo Falls Dam on the Barron River (330,000 acre feet) has been completed, and construction is nearing completion on irrigation works to serve 78,000 acres (comprising 910 tobacco farms and 180 mixed farms), of which 49,000 acres will be irrigated. One hundred and ninety-eight miles of channels have been constructed, and irrigation water from the dam is available to 548 farms. Tinaroo Falls Dam is also providing a regulated flow of water in Barron River at Kuranda for the generation of hydro-electric power at Barron Falls.

Burdekin River Irrigation Area. The Clare, Millaroo and Dalbeg sections of the Burdekin River Irrigation, Hydro-electric and Flood Mitigation Project have been completed. Located from twenty-five to sixty-five miles from the mouth of the Burdekin, these areas comprise 18,862 acres and obtain water from central pumping stations drawing from the river. Two storages of 7,670 acre feet and 2,550 acre feet capacity have been constructed about seventy-nine miles and seventy-two miles respectively from the mouth of the river. Sugar cane production predominates in the area.

Dawson Valley Irrigation Area. A scheme for the development of the Dawson Valley providing for the irrigation of 70,000 acres was inaugurated in 1923, but work was discontinued after three weirs had been built in this area. Their total storage is 10,280 acre feet, covering about sixty-one farms (4,894 acres) in production. Cotton and grain account for the major part of the production from irrigated areas. Further development of the scheme is dependent on the provision of additional storage works.

St George Irrigation Area. This area comprises twenty farms, on which some 6,200 acres are being irrigated from a weir on the Balonne River (8,200 acre feet). Fat lambs, wool, and fodder and cotton crops are the main products. Approval has been given for the construction of additional storage and the provision of irrigation and other works to serve a further thirty-two farms. The major storage, to be built on the Balonne River (Kajarabie Dam), will have a capacity of 81,000 acre feet.

Several additional projects have recently been completed and work is in progress on others. Moogerah Dam (Warrill Valley Project) on Reynolds Creek (75,000 acre feet) is capable of serving some 7,000 acres of the Warrill Valley, and is providing water for the thermal power station now under construction at Swanbank, near Ipswich. Borumba Dam (Mary Valley Project) on Yabba Creek (34,500 acre feet) makes water available to maintain the town water supply for Gympie and allows extension of the area irrigated from the Mary River to about 18,000 acres. Callide Dam (37,800 acre feet) on Callide Creek, nine miles upstream from Biloela, will provide cooling water for the Calcap power station and compensation water for maintenance of underground supplies along Callide Creek; provision has been made to increase the storage capacity to 87,000 acre feet. Leslie Dam (Upper Condamine Project), on Sandy Creek, has an initial capacity of 38,200 acre feet, with provision for later increase to 87,000 acre feet. Water from the dam is available for irrigation of sections of the Darling Downs downstream the Condamine River as far as Cecil Plains and for a supply to the city of Warwick. A 61,000 acre feet dam under construction at Coolmunda (Macintyre Brook Project) will allow irrigation of up to 8,000 acres. Wuruma Dam (Upper Burnett Project), under construction on the Nogoa River, will have a storage capacity of 157,000 acre feet for irrigation of 11,000 acres along 100 miles of the Burnett River. The Eungella Dam (Bowen-Broken Project), under construction on the Broken River, will have a storage capacity of 104,000 acre feet. It will provide cooling water for the Collinsville power station and irrigation water along the Bowen and Lower Burdekin rivers. The development of rivers constituting portion of the Queensland-New South Wales border, under the authority of the Dumaresq-Barwon Border Rivers Commission, is described on page 966.

Rural Water Supply Areas

Although provisions existed in the Water Acts for many years for the constitution of rural water supply Areas and Boards, little advantage was taken of these powers until 1964 when an amendment of the Acts extended the purposes for which these Areas and Boards may be constituted and the methods of rating and financing of works, and provided for resumption or acquisition of lands by such Boards. This form of water supply is being sought increasingly by groups of landholders in various parts of Queensland to provide a reasonably economical measure of permanent supply for stockwatering, dairy and domestic purposes in areas prone to drought, and thus achieve a permanent form of drought relief. Usually the capital cost of works is met by a 50 per cent subsidy by the Government and the balance by a Board borrowing by Government guaranteed loan on the security of debentures.

At present six Rural Water Supply Areas, Grevillea, Back Creek, Brigooda, Tarampa, Coreen, and Roadvale are operating, supplying 243 holdings, covering 106,000 acres and reticulated by ninety-seven miles of pipelines. Other schemes are in course of construction at Proston, Kooingal and Merlwood; these will supply a further 254 consumers by 128 miles of pipelines and serve 86,200 acres.

Water conservation, irrigation and drainage schemes may also be carried out under these Acts, and two group irrigation proposals and ten group drainage proposals are currently under investigation. No subsidy has yet been considered for these proposals.

Underground water—Great Artesian Basin and other sources

The use of underground water supplies has been a very important factor in agricultural and pastoral development in Queensland. The Great Artesian Basin is the major source of stock water supplies over more than half the State. Elsewhere, supplies obtained at shallower depths, in porous, fractured or fissured rocks, are extensively used for domestic and stock purposes. Underground water also supports more than half the irrigated area in the State, supplies being obtained chiefly from alluvial formations along river valleys, and from river deltas, the most conspicuous example of which is the Burdekin River (*see* page 977).

Great Artesian Basin

Western Queensland, beyond the 20-inch rainfall belt, is predominantly pastoral and is mainly dependent for water supplies on artesian and sub-artesian bores and, where surface storage is not

readily available, on excavated tanks. The Great Artesian Basin in Queensland corresponds approximately with the area lying west and south of the Great Dividing Range, excluding the Cloncurry mineral field and the Barkly Tableland. It comprises 421,000 square miles or nearly two-thirds of the total State area of 667,000 square miles.

Artesian water. Although the number of bores has gradually increased over the years, the total flow of all bores has declined from the peak flow of 351 million gallons a day. A report on the nature and structure of the Great Artesian Basin, presented in 1954, indicated that the output would continue its decline during the next sixty years, at which stage the flow from the remaining flowing bores would be of the order of 110 million gallons a day. The discharge from windmills, springs and other leakages, together with the underflow past the Queensland borders, would then be about 20 million gallons a day. It was further expected that the total discharge, of the order of 130 million gallons a day, would be in equilibrium with the recharge of the basin. It was expected that numbers of bores on higher ground would cease to flow during the next sixty years and the area served by the flowing bores would contract by perhaps twenty per cent.

Up to 30 June 1967, 3,012 artesian bores had been drilled, of which 1,980 were still flowing. The total depth drilled amounted to 4,215,558 feet and the estimated daily flow was 197 million gallons. Although very few bores exceed 2,000 feet in depth (the average depth is 1,400 feet) and a new bore greater than 4,000 feet deep is exceptional, the deepest bore recorded was sunk to 7,009 feet. Some bores which had been classified as 'ceased' have been inspected and found to be still flowing, while other ceased bores have responded to deepening and have recommenced flowing. Both the pressure and flow of artesian bores are steadily diminishing, the rate of decrease varying widely throughout the basin. Present average rates of diminution are: pressure, 1–2 feet of head; total flow, 2–3 per cent per annum. The greater part of the artesian discharge is distributed by some 15,500 miles of open earth channels, from which a large proportion of water is lost by soakage and evaporation, less than 10 per cent being actually used by stock.

Although artesian beds underlie a large area of the State, only 79,000 square miles are primarily watered by bore drains. The remaining area is watered by artesian bores (with small or no flow and limited drains), sub-artesian bores, excavated tanks, dams, and natural waterholes. At the present time an increasing use is being made of pipelines for the reticulation of artesian water. In many districts artesian bores do not provide economical watering facilities because of depth, limited area to be watered, and difficult terrain for distribution of water by drains. The quality of artesian water from the greater part of the basin is not suited for prolonged use for irrigation on most soils, nor are the supplies sufficient for both large scale irrigation and stock-watering. Practically the whole of the final steady-rate discharge from flowing bores will be needed for the watering of stock.

Shallower supplies, which come from beds unconnected with artesian beds, are of variable quality and volume. These supplies are available at depths of less than 1,000 feet over a large area of the basin. A total of 12,082 sub-artesian bores within the Great Artesian Basin have been registered in Queensland. An important practical consideration is that the main artesian beds are continuous and the sub-artesian beds are not continuous.

Bore Water Areas. The constitution of Bore Water Areas was inaugurated in 1913 to aid pastoral settlement in districts where large flows were available at a cost beyond individual capacity, and to conserve artesian supplies by fully utilising flows from the existing bores on the land resumed for closer settlement. Bores and drains are constructed from loan funds repayable over a period of years. The areas are administered by local boards or by the Commissioner of Irrigation and Water Supply, acting as a board. Rates are levied to meet interest, redemption, maintenance and administration costs. Statistics for the year 1966–67 are: areas constituted, 74; administered by the Commissioner, 55; administered by local boards, 6; number abolished, 13; area benefited, 4,806,757 acres; average rate per acre, 1.07 cents; number of flowing bores, 59; total flow, 24,753,000 gallons a day; drains served, 2,515 miles.

Other underground sources

Outside the Great Artesian Basin, ground water supplies can conveniently be divided into two broad groupings, (*a*) those obtained in porous, weathered, fissured, or fractured rocks, and (*b*) those obtained in unconsolidated sediments of Cainozoic age. In the first group, supplies, often within short distances, are widely variable both in quantity and quality, but are normally sufficient only for stock-watering purposes. Because storage is generally small, seasonal fluctuation of water level tends to be high, and this can have a significant effect on the supply available during dry seasons. Small to moderate irrigation supplies (up to a few thousand gallons an hour) are sometimes obtained, and, in exceptional cases, particularly with basalts and limestones, supplies may be as much as 10,000 gallons an hour. The second group comprises the main irrigation supplies, and, although a wide range may be found in the supply normally available from individual bores in any area, pumping rates as high as 10,000 gallons an hour are common. The availability of underground water has been investigated in a

considerable number of alluvial valleys in south-eastern Queensland and in a number of coastal areas, particularly in the vicinity of the estuaries of the Burnett, Pioneer, Haughton, and Burdekin Rivers, where underground water is the main source for irrigation of sugar cane.

Reference has already been made to the importance of underground water for irrigation in the Lockyer and Callide Valleys (*see* page 977). Other areas in which irrigation supplies from alluvial formations have been extensively utilised include the Monto area, parts of Barker and Barambah Creeks, Warrill Creek, Cressbrook Creek, the Upper Logan River, Don River (Bowen), Bremer River, and parts of the Condamine River and its tributaries. Government authorities do not normally undertake private drilling for landholders, but assistance is given in the location and development of ground water supplies through the provisions of '*The Farm Water Supplies Assistance Acts*, 1958 *to* 1965' (*see* below). This assistance has considerably accelerated the use of underground water for irrigation, and there is no doubt that there are many areas with a large potential for future expansion.

Stock watering

A predominant interest in the field of water conservation has been the provision of stock and domestic water supplies in Queensland's great pastoral areas, which contain more than a third of the Commonwealth's cattle and about an eighth of the sheep. In addition to the stabilisation of water supplies in the pastoral areas, the provision of water along stock routes for travelling stock has received much attention in recent years.

Main stock routes. The Queensland Irrigation and Water Supply Commission acts as consultant and constructing authority to the Stock Routes Co-ordinating Board for watering facilities on stock routes. On completion, facilities are vested in local authorities for control and maintenance. From 1935, when the scheme was inaugurated, to 30 June 1967, 667 facilities had been completed, and at 30 June 1967, seventeen facilities were under construction or investigation. A State-wide investigation is being carried out by the two authorities mentioned above to ascertain the general movement of stock, determine primary and secondary routes, register existing water facilities, and formulate a co-ordinated plan in regard to the provision of new watering facilities.

Channel Country stock routes. Under the *States Grants (Encouragement of Meat Production) Act* 1949–1954 the Commonwealth Government agreed to meet half the cost of providing additional watering facilities in stock routes leading into, along, and out of, the Channel Country and on the route from Camooweal to Mount Isa. These routes connect with the main far-western route included in the State scheme inaugurated in 1935. Under this scheme, which was completed during 1962–63, thirty-seven watering facilities have been constructed, at a total cost of $599,184.

Technical and financial assistance to farmers

'*The Farm Water Supplies Assistance Acts*, 1958 *to* 1965' are designed to improve the standard of water supply installations on individual holdings, encourage greater development in individual irrigation schemes, provide greater stability of production, and avoid losses in time of drought as well as generally increase production. To achieve this purpose, the Acts authorise the provision of technical and financial assistance to landowners for the investigation, design and installation of approved works of farm water supply. All projects for which finance is provided under the Acts are carried out under Commission guidance, and for the payment of a small charge the Commission will advise on the construction of works designed by its staff, but for which the landowners do not require financial assistance under the acts.

During 1966–67, 730 requests (541 for technical assistance only and 189 for technical and financial assistance) were dealt with in addition to advice on a further 519 requests on ground-water supplies. An amount of $1,015,521 was approved for advances under the Acts in 1966–67, and the amount advanced was $799,664.

South Australia

Brief particulars of the climatic conditions in South Australia are given on page 1129 of Year Book No. 37. (*See also* the chapter Physical Geography and Climate of this issue.)

Administration

Water supplies, other than irrigation works, are under the control of the Engineering and Water Supply Department, which administers the Waterworks Act, 1932–1966 and Water Conservation Act, 1936, both of which empower the Minister of Works to impound or divert the water from any lake, watercourse or underground source for the purpose of establishing and maintaining public water supply schemes. The Waterworks Act, 1932–1966 governs the principal reticulated water supplies in proclaimed water districts throughout the State. A feature of these supplies is the extensive network of water mains supplying country townships and farmlands where local water resources are practically non-existent.

Under the Water Conservation Act, 1936, small dams, wells, bores, rainsheds, storages and, in some instances, minor reticulation works are provided in remote areas to assist local settlers in development and to supply travellers and travelling stock.

Irrigation

Australian irrigation originated in the upper Murray in South Australia and the Mildura area of Victoria. South Australian irrigation commenced with an agreement between the Government and the Chaffey brothers in 1887 whereby an area of land at Renmark was made available for the establishment of certain irrigation works. In South Australia, irrigation is almost exclusively confined to the Murray Valley. Except for quantities held in various lock pools, no water from the Murray is stored in South Australia. Water is either pumped onto the land or gravitated from the river.

The two major authorities administering irrigation areas are the Department of Lands and the Renmark Irrigation Trust. The Trust is controlled by a local board of management consisting of seven members. This area differs from other South Australian irrigation areas in that the land is freehold instead of leasehold and is self-contained and self-controlled. Every settler is entitled to vote for the election of Trust members. The Trust maintains eighty miles of reticulation channels.

The following table shows particulars of the areas of crops and pastures irrigated in the various areas during 1966–67 and in South Australia as a whole during the seasons 1962–63 to 1966–67.

AREA OF LAND IRRIGATED: SOUTH AUSTRALIA, 1962-63 TO 1966-67

(Acres)

Season and authority	*Vine fruits*	*Tree fruits*	*Citrus fruits*	*Other crops (a)*	*Pastures*	*Total*
1966–67—						
Department of Lands Irrigation Areas—						
Orchard land—						
Berri	4,702	1,412	1,609	..	..	7,723
Cadell	482	222	183	..	..	887
Waikerie	1,592	807	1,453	..	..	3,852
Cobdogla	4,425	255	345	..	..	5,025
Moorook	303	115	282	..	..	700
Kingston	141	51	278	..	..	470
Mypolonga	..	271	530	..	..	801
Chaffey-Ral Ral Division	757	246	13	..	..	1,016
War service land settlement—						
Chaffey-Cooltong Division	392	200	577	..	..	1,169
Loxton	3,271	785	2,184	..	..	6,240
Cobdogla-Loveday Division	228	35	38	..	..	301
Reclaimed swamp land—						
Monteith	..	..	..	..	986	986
Mypolonga	..	..	..	..	1,306	1,306
Wall	..	..	..	..	512	512
Murray Bridge–Burdett Division	..	..	..	..	109	109
Mobilong Division	..	..	..	..	432	432
Long Flat	..	..	..	..	341	341
Neeta	..	..	..	..	561	561
Pompoota	..	..	..	..	425	425
Cowirra	..	..	..	..	571	571
Jervois	..	..	..	..	3,688	3,688
Total, Irrigation Areas	*16,293*	*4,399*	*7,492*	..	*8,931*	*37,115*
Renmark Irrigation Trust	5,550	1,904	1,651	136	125	9,366
Private landowners	6,425	16,676		35,925	33,250	92,276
Total, 1966–67	**28,268**	**32,122**		**36,061**	**42,306**	**138,757**
1965–66	28,850	31,089		27,302	41,594	128,835
1964–65	28,286	30,094		28,795	35,964	123,139
1963–64	27,954	28,787		38,193	22,936	117,870
1962–63	27,384	26,876		36,745	21,808	112,813

(a) Includes fodder and fallow land.

Water supply schemes

Adelaide Metropolitan Water Supply. Adelaide and surrounding areas of development including Elizabeth derive their water from eight reservoirs in the nearby Mount Lofty Ranges and by means of pumping stations and a pipeline from the Murray River at Mannum. The reservoirs have a storage capacity of 97,400 acre feet and the pipeline has a capacity of 88,000 acre feet a year. The consumption for the whole area for the year 1966–67 was 102,900 acre feet, equivalent to a consumption of 100 imperial gallons per head per day. The capital cost to 30 June 1967 was $110,276,000.

Country reticulated supplies. Areas extending to a distance of 90 miles north of Adelaide are supplied from the Warren, Barossa and South Para Reservoirs (50,350 acre feet) in the Barossa Ranges. Supplies to these areas are supplemented by River Murray water delivered into Warren Reservoir through a branch from the Mannum–Adelaide pipeline. A pipeline to pump water from the River Murray at Swan Reach directly into the Warren Trunk Main at a point near Stockwell is at present under construction. Agricultural towns and areas further north are supplied from Beetaloo, Bundaleer and Baroota Reservoirs, and the Morgan–Whyalla Pipeline. The original 223-mile pipeline from Morgan to Whyalla and a second and larger pipeline completed in 1966 are at present able to carry 30,000 acre feet of water a year from the River Murray. The ultimate designed capacity of the two pipelines is 61,000 acre feet per year. A large part of Eyre Peninsula is supplied, through the 240-mile Tod River Main and the 104-mile East Coast Main, with water from the Tod River Reservoir (9,160 acre feet), the sand beds of the Uley-Wanilla Basin, the Lincoln Basin, and Polda Basin. Along the Murray River all towns are supplied from the river. Water from the river is also reticulated through adjacent farmlands for up to 30 miles, and a pipeline currently being extended from Tailem Bend to Keith will provide the means of reticulating Murray water to numerous towns and a large area of farmlands in the upper south-east. Surface and underground resources have been developed to supply most rural centres not covered by the larger schemes. Water conservation and distribution works in country districts to 30 June 1967 have cost $125,346,000 (exclusive of river control and irrigation works on the Murray River) and contain 7,903 miles of water mains.

Underground water

Underground water supplies in South Australia come under the supervision of the Department of Mines, which has explored for and developed groundwater supplies in South Australia for many years. This search has involved geological surveys throughout much of the State, supported by drilling operations carried out by departmental drilling plants.

By virtue of the Underground Waters Preservation Act, 1959–1966, the Department of Mines is empowered to exercise control over water boring operations and groundwater usage in 'defined areas'. There are at present two such areas, the North Adelaide Plains and the Kingston–Beachport area in the south-east of the State.

Results of groundwater surveys are published from time to time as Bulletins or Reports of Investigation of the Department of Mines. The *Groundwater Handbook*, published in 1959, outlines the basic principles controlling the occurrence of groundwater and the methods of drilling for, and development of, groundwater supplies.

In the north-east of the State, the deepest section of the Great Artesian Basin is not extensively developed because development costs are high in proportion to land utilisation capacity. Deep boreholes have been drilled by the Government to provide water along stock routes, and pressure waters have been utilised around the basin margin. Waters from the South Australian section of the Great Artesian Basin are generally suitable only for stock use because of their salt content. The marginal waters occur at comparatively shallow depth, as at Maree township, where the artesian bore is 575 feet deep. In addition to pressure waters, non-pressure waters are sometimes obtainable at shallower depths and these provide pastoralists with stock water supplies which can be readily and economically developed.

Usage of groundwater of the Murray Basin has allowed development of the Murray-Mallee country and the south-east of the State. Mount Gambier draws its water supply from the Blue Lake, which is fed from the Basin, and many other townships obtain their water supplies from boreholes.

About 100 boreholes tap an artesian aquifer in the Kingston–Beachport area, where flow rates have exceeded 50,000 gallons per hour in some areas. This water has been extensively used for flood irrigation on improved pastures. Intensive development of the artesian aquifers in this area has resulted in falling flow rates and water levels over the past few years, and it has been found necessary to declare this area a 'defined area' in the terms of the Underground Waters Preservation Act, 1959–1966.

On Eyre Peninsula, the Uley–Wanilla Basin has been a source of groundwater since 1948, but by 1963 the water level had lowered critically, and pumping was suspended until 1966. The Lincoln Basin is now fully developed, yielding up to 20 million gallons per week, and providing water for the

town of Port Lincoln since 1960. Development of the Polda 'aeolianite' aquifer began in 1962. This basin is centred 25 miles west of Lock. The present pumping plant has a capacity of 7 million gallons per week. The water is reticulated to towns and farming properties on the Upper Eyre Peninsula. Large diameter boreholes are each capable of yielding 20,000 gallons per hour. Investigations of the aeolianite aquifer are currently being undertaken in County Musgrave, to the west of the Polda area. Investigations of the South Uley Basin have been completed; one borehole yielded 100,000 gallons per hour, but a safe yield of 22,500 gallons per hour was recommended to safeguard against aquifer depletion.

Pastoralists, farmers, market gardeners, and others have been assisted with advice on drilling, and the Department of Mines maintains and operates 24 drilling plants, which to date have developed an underground water supply potential in excess of 150 million gallons a day throughout the State. The whole of the Murray River Basin has been examined critically to ascertain the extent of land which could be used for lucerne, and considerable tracts of previously undeveloped country in the upper south-east Yorke Peninsula have been found to have usable water and have been opened up.

Farm water schemes

The Department of Mines gives assistance to individual farmers in the provision of supplies from underground sources, and the Department of Agriculture provides an advisory service on water conservation and irrigation designs, on farms, and on the suitability of underground water for irrigation and stock purposes. In addition, a great part of the farming areas is supplied with water under pressure from the extensive distribution systems connected to various reservoirs and the Murray River.

South-eastern drainage

In the south-east of South Australia it has been necessary to construct drainage schemes to dispose of surplus water from areas where a series of valleys or flats is separated by low ranges, parallel to the coastline, which prevent natural drainage. The Millicent Drainage System, completed in 1885, reclaimed 100,000 acres. The South-Eastern Drainage Area System, which is controlled by the South-Eastern Drainage Board, comprises drains constructed by the Government at national cost, plus those undertaken by the Government in co-operation with the landholders. The area is bounded on the east by the State boundary, and on the west by the sea coast. It extends from about 55 miles north of Kingston, southerly to near Millicent and Kalangadoo. Up to 1948 about 430 miles of drains had been provided at a cost of $1,441,752. These were of a developmental nature intended more to promote the rapid removal of floodwaters than to provide a complete system of drainage. Since 1948 the complete drainage of the Biscuit, Reedy Creek and Avenue Flats in the Western Division has been in progress. The southern section of 260,000 acres, which involved the excavation of 8,100,000 cubic yards and the provision of 343 miles of new or enlarged drains, has been completed. Work on the northern section of 140,000 acres is virtually complete with the construction of 85 miles of drains which involved the excavation of 2,989,880 cubic yards of material. In addition, work is in hand for the drainage of 727,000 acres of land in the Eastern Division of the south-east, situated east of Bakers Range, and extending from near Kalangadoo to north of Naracoorte. Part of the first stage of this work provided for the construction of a main diversion drain (consisting of the enlargement of an existing drain for a distance of 24 miles and the excavation of 22 miles of new drain) from Beachport to Struan. The work to date has required the excavation of 6,329,600 cubic yards of material; the total length of the diversion drain is 46 miles. Work is proceeding on the internal drainage of the area, and 267,200 cubic yards of excavation have been carried out in constructing 9½ miles of new drains and enlarging existing drains. The capital cost of drainage in the South-Eastern Drainage Area System to 30 June 1967 was $17,128,300, and the length of drains constructed was 835 miles. An extensive system of private drains (many of which are connected to the drains constructed under Government authority) also exists in the south-east of the State.

Murray River Irrigation District

Excess waters from the irrigation of orchards in the Murray River Irrigation Districts are building up a perched water table, which is rising to the levels of the tree root system. Investigations have proved that adequate drainage can be obtained in the underlying limestone aquifer. The building up of groundwater pressures due to drainage in these aquifers is being studied, as the outflow of saline waters into the Murray River surface waters must be prevented.

Western Australia

Brief particulars of the climatic conditions in Western Australia are given on page 1133 of Year Book No. 37. (*See also* the chapter Physical Geography and Climate of this issue.)

Administration

The Minister for Water Supply, Sewerage and Drainage administers the departmental irrigation schemes under the *Rights in Water and Irrigation Act, 1914–1964*. He is advised by an Irrigation Commission representing the local irrigationists and governmental, technical and financial branches. He also administers, under the *Country Areas Water Supply Act, 1947–1964*, the water supplies to 216 towns and 4,200,000 acres of reticulated farmland. As Minister for Works he controls minor non-revenue producing supplies to stock routes and a few mines and agricultural areas with their associated communities. Five town supplies are administered by local boards under the *Water Boards Act, 1904–1964*, which provides a large degree of autonomy with ultimate Ministerial control.

Irrigation

Irrigation schemes have been established by the Government on the coastal plain south of Perth in the Waroona, Harvey and Collie River Irrigation Districts between Waroona and Dardanup, the water being channelled from dams in the adjacent Darling Range.

Logue Brook Dam with a capacity of 19,717 acre feet, Harvey Weir (6,495 acre feet) and Stirling Dam (46,191 acre feet) supply the Harvey Irrigation District, the rated area of which is 13,290 acres. The Harvey District links up with the Waroona Irrigation District, which is served by Waroona Dam (12,105 acre feet), Drakes Brook Dam (1,855 acre feet) and Samson Brook Dam (7,437 acre feet) and comprises a rated area of 3,060 acres. Wellington Dam on the Collie River with a capacity of 150,107 acre feet serves an area of 10,870 rated acres in the Collie River Irrigation District. Pastures for cattle comprise 89 per cent of water usage in these districts.

During the past thirty years a centre of tropical agriculture has been developed at Carnarvon, near the mouth of the Gascoyne River. Private pumping from sands of the Gascoyne River is the principal source of irrigation water for the 158 plantations. Because of the high risk of drawing in surrounding saline ground waters by over-pumping, the usage of water by the planters is controlled strictly by the Government. The Government is developing up-river sources and delivers water by pipeline to 23 plantations in the district. Bananas for the Perth market and fruit and vegetables for the Perth and Adelaide markets are the principal crops. A tropical research station is maintained at Carnarvon by the Department of Agriculture.

A project has been embarked upon to provide water supplies for irrigation in the area traversed by the Ord River in the Kimberley Division. The project provides for the eventual development of an area of 178,000 acres of land agriculturally and topographically suitable for irrigation, and comprises four stages. The first stage is now complete with 30,000 acres of the district supplied from the Diversion Dam which holds 80,000 acre feet of water. Thirty farms averaging 660 acres each have been developed for cotton growing in addition to the original 2,400-acre pilot farm. The remaining stages envisage the construction of an earth and rock-fill structure storing 4.6 million acre feet of water (equivalent to approximately 1,250,000 million gallons), a distribution irrigation network to serve a further area of 148,000 acres, approximately one-third of which is located in the Northern Territory, and the construction of a hydro-electric power station at the site of the Main Dam.

On the Liveringa flood plain, water is diverted from the Fitzroy River through Uralla Creek to a natural storage of about 1,200 acre feet, which, together with a dam on Uralla Creek (4,600 acre feet), provides for irrigation at Camballin 65 miles south-east of Derby. Irrigated crops of rice and sorghum are grown in the area.

AREA OF LAND IRRIGATED: WESTERN AUSTRALIA, 1962-63 TO 1966-67
(Acres)

Season	*Vegetables*	*Fruit*	*Vineyards*	*Cotton*	*Other crops(a)*	*Pastures*	*Total*
1962–63 . .	9,375	9,588	924	(*b*)	4,447	27,167	51,501
1963–64 . .	9,166	10,425	966	1,526	6,153	26,958	55,194
1964–65 . .	9,379	11,710	1,081	5,496	5,259	30,110	63,035
1965–66 . .	9,944	11,566	844	8,307	6,707	30,039	67,407
1966–67 . .	9,770	11,704	795	11,892	4,676	31,790	70,627

(*a*) Includes fodder crops. (*b*) Not available for publication, included with Other crops.

Country water supplies controlled by Department of Public Works and Water Supply

Since 1947 enlargement and extensions of the Goldfields and Agricultural Water Supply and the development of the Great Southern Towns Water Supply have been carried out, mainly in accordance with a project known as the Modified Comprehensive Scheme. Under this scheme water has been supplied to towns and farms in an area of 4.1 million acres in mixed farming (cereal

and sheep) districts of Western Australia. The modified scheme was completed in 1961 at a cost of $20.6 million, of which the Commonwealth contributed $10 million under the *Western Australia Grant (Water Supply) Act* 1948. A further request was made by the State Government in 1963 for a grant of $10.5 million representing half the estimated cost of proposed extensions which would increase by 3.7 million acres the area served by the scheme. The Commonwealth agreed to provide assistance in the form of an interest-bearing loan up to a maximum of the amount requested, advances to be made during a period of eight years commencing 1965–66. Legislative authority for the loan is given by the *Western Australia (South-west Region Water Supplies) Agreement Act* 1965.

Mundaring Reservoir on the Helena River, 26 miles from Perth, is the source of water supplied to the Eastern Goldfields. It has a capacity of 62,435 acre feet and is connected to Kalgoorlie by a pipeline with extensions to towns and agricultural areas. At 30 June 1967 the Goldfields and Agricultural Water Supply was serving 116 towns and localities, and water was being reticulated to farms in an area of 4.8 million acres. The total length of pipelines was 4,029 miles and the number of services was 25,554. Consumption during 1966–67, including supplies drawn from local schemes and from the Metropolitan Water Supply, was 2,974 million gallons.

The Great Southern Towns Water Supply pipes water from Wellington Dam to towns on the Great Southern Railway from Brookton to Katanning as well as a number of other towns. At 30 June 1967 the Supply was serving 24 towns, the total length of pipelines was 452 miles, and the number of services was 8,161. Consumption during 1966–67, including supplies drawn from local sources, was 840 million gallons.

One hundred and one local schemes supply water from stream flow, dams, tanks, wells, and bores, mainly to country towns. At 30 June 1967 the total length of water mains was 833 miles and the number of services was 23,745. During 1966–67 consumption was 2,061 million gallons.

Other country water supplies

As well as the schemes controlled by the Department of Public Works and Water Supply, there are five local Water Boards which draw supplies from stream flow, dams, wells, and bores. In addition, some local authorities supply water within their boundaries. The Forests Department and sawmilling companies operate schemes to supply water to their mill towns. Railways of the Commonwealth and State Governments make independent provision for supplies of water for their own purposes, although considerable additional quantities are consumed by the railways from other sources, such as those controlled by the Department of Public Works and Water Supply and the Metropolitan Water Supply, Sewerage and Drainage Board.

Underground water

Considerable use is made of underground water by individual farmers, pastoralists, market gardeners, etc., and it is estimated that over 50,000 bores are in use in the State. The quality of the water varies from place to place and much of it is too saline for irrigation or even stock. However, artesian aquifers are tapped to supply or augment the town supplies of Perth, Bunbury, Busselton, Eaton, and Denham, and non-pressure water is used in the public supplies of 37 other towns.

Considerable advances in the knowledge of aquifers and quality of water in the main sedimentary basins have been made as a result of extensive geological surveys by oil exploration companies and exploratory drilling by the Mines Department.

The Public Works Department and the Metropolitan Water Supply, Sewerage and Drainage Board are responsible for development work. The Geological Survey Branch of the Mines Department is responsible for all exploratory works, as well as for investigating and assessing the State's groundwater resources, advising local Government authorities, private industry and individuals on groundwater problems, and supervising departmental drilling.

Groundwater exploration projects are in progress or have recently been completed for the towns of Port Hedland, Exmouth, Geraldton, Morawa, Jurien Bay, Yunderup, Mandurah, Albany, Esperance and Watheroo, and additional supplies have been located for the Perth metropolitan area. A long-term systematic exploratory drilling programme in the Perth Basin is continuing.

Tasmania

Brief particulars of the rainfall pattern in Tasmania are given on page 1136 of Year Book No. 37. (*See also* the chapter Physical Geography and Climate of this issue.)

Main purposes of water conservation and utilisation

Because of the generally more adequate rainfall in Tasmania, scarcity of water is not such a problem as it is in most mainland areas, though not all streams are permanently flowing. The only large scale conservation by reservoirs is for hydro-electric power generation, but there are

some moderately sized dams built by mining and industrial interests and by municipal authorities for town water supplies. 'Run of the river' schemes are quite adequate for assured supply in many municipalities.

Until a few years ago irrigated areas were negligible except for long established hop fields, but there is a rapidly expanding use of spray irrigation on orchards, pastures, potatoes, and beans. Until recent years there has been almost complete dependence on natural stream flows, but the need for some regulating storages has become apparent. Increasingly, farmers are constructing storages of their own, and the extension of this practice is foreseen as the logical solution in most areas, as valleys are narrow and steep sided. Single large reservoirs cannot economically serve large areas of suitable land, as nearly every valley is separated from others by pronounced hills, prohibiting the construction of cross-country channels.

Underground water suitable for stock, minor irrigation works and limited domestic use is exploited in the consolidated rocks of south-east, midlands and north-western Tasmania. In the midlands and south-east of the State nearly all groundwater is recovered from Permian and Triassic rocks. In the north-west, water is recovered from a variety of rocks ranging from Precambrian dolomites, quartzites and schists to Tertiary basalt. The Precambrian rocks are the highest yielding consolidated rocks. The basalts have been shown to be reliable aquifers yielding good quality water.

Some water is also obtained in the unconsolidated Tertiary sediments of the central north. These sediments, which are dominantly clay, yield fairly saline water. Water is thought to be contained in hair-line shrinkage fractures in weathered clays. Underground water investigations are carried out by the Mines Department and a drilling programme is currently in progress with the object of assessing the stratigraphy and reserves of the basins. Gravel zones between basalt flows in the north-west yield up to 5,000 gallons per hour. On King and Flinders Islands water of variable quality suitable for stock and limited domestic use is obtained from aeolian sands. The township of Currie on King Island obtains up to 200,000 gallons a day for domestic use from this source. The Palaeozoic mudstones and tertiary sediments of the north-east are being explored as a source of water.

Groundwater projects have been recently completed in the Cygnet district, and work is in progress in the Longford basin and the Coal River basin.

Administration

In Tasmania, water supply was once exclusively the responsibility of local government authorities, but two statutory authorities now operate bulk supply schemes, piping water for distribution by the local government authorities in the Hobart and Launceston regions, and directly to certain industrial consumers. The Rivers and Water Supply Commission is empowered to take water at streams and lakes, or to issue others with licences to do so; licensing covers supply to specific industries and municipalities as well as ordinary riparian rights. The Commission is concerned with drainage trusts' operations, river improvements (including repairs after flood damage), stream gauging, and its own regional water schemes.

The second body, the Metropolitan Water Board, has overall control of water supplies to the cities of Hobart and Glenorchy and the municipalities of Kingborough and Clarence; these authorities, however, are responsible for reticulation. The Board also controls a second scheme serving other southern municipalities. In the rest of the State, water supply is still completely a function of local government, subject to the approval of plans and finance by the Rivers and Water Supply Commission.

Regional water schemes

Four regional water schemes are in operation. The first draws water from the east bank of the River Derwent at Lawitta to provide domestic and industrial supplies in five southern municipalities, and the second, which increases existing supplies to Hobart and suburbs, pumps water from the west bank of the River Derwent at Lawitta. These two schemes are controlled by the Metropolitan Water Board. In addition, the State Government has constructed two other regional water schemes; the first, to serve the aluminium refinery at Bell Bay on the eastern bank of the River Tamar and to supply bulk water to several municipalities; the second, to supply water along the western bank of the Tamar. The two northern schemes are the responsibility of the Rivers and Water Supply Commission.

Potential sources capable of greater development without storage exist on the Derwent, South Esk, Huon, Lake, Mersey, and Forth Rivers. There is also a great reserve of untapped permanent streams in the western half of the State, which is largely unsettled. The State's largest rivers discharge in the west, but diversion to the eastern half of the watersheds is not regarded as practicable.

Industrial water schemes

Three principal industrial water schemes have been installed privately—for a paper mill near Lawitta on the Derwent River, for a paper mill at Burnie using water from the Emu River, and for a factory at Heybridge reticulating water from Chasm Creek. The State Government has constructed

some water schemes for use primarily for industrial purposes. These include the scheme serving the aluminium refinery at Bell Bay referred to above, a storage supplementing the summer flows of the Kermandie River for use by a wood-pulping plant at Geeveston, and the recently completed Prosser River Scheme which supplies water to a sodium alginate industry at Louisville near Orford and supplements the water supply of the township of Orford.

Irrigation

There are no State irrigation projects at present, but the Rivers and Water Supply Commission is investigating the possibility of establishing several schemes, notably in the Cressy area, the Huon region, and the valleys at the Jordan and Coal rivers. The *Water Act* 1957 provides for irrigation works to be undertaken by municipalities and by trusts constituted for the purpose, but no such works have been undertaken to date. With the exception of the Lawrenny estate at Ouse, which is the largest single area under irrigation in the State, and also the only formally constituted irrigation district, there are no extensive schemes utilising one common source of water supply in Tasmania. The larger proportion of the area under irrigation is watered by pumping systems.

AREA OF LAND IRRIGATED: TASMANIA, 1962-63 TO 1966-67
(Acres)

Season	*Vegetables*	*Fruit*	*Hops*	*Other crops(a)*	*Pastures*	*Total*
1962–63 . . .	4,100	4,446	1,465	2,839	11,435	24,285
1963–64 . . .	6,319	5,933	1,463	4,162	15,693	33,570
1964–65 . . .	8,302	5,955	1,553	4,318	14,194	34,322
1965–66 . . .	12,994	7,241	1,524	5,786	17,651	45,196
1966–67 . . .	12,979	8,287	1,495	6,353	18,111	47,225

(*a*) Includes fodder and fallow land.

Northern Territory

Some particulars of the climate and main topographical features of the Northern Territory are given on page 1138 of Year Book No. 37, and in this issue information on climatic conditions will be found in the chapter Physical Geography and Climate, and a brief outline of contour and physical characteristics in the chapter The Territories of Australia.

Administration

Under the *Control of Waters Ordinance* 1938–1965 of the Northern Territory, natural waters are vested in the Crown. Where a watercourse or lake forms a boundary of any land alienated by the Crown, the beds and banks are deemed to remain the property of the Crown (except in special cases) and the diversion of water is prohibited except under prescribed conditions. There is a Water Resources Branch of the Northern Territory Administration under the control of a Director. The functions of the branch include systematic stream gauging, collection of data on surface and underground water supplies, planning of water use for irrigation and town water supplies, and flood prevention and control.

Under the *Water Supplies Development Ordinance* 1960–1963 the Water Resources Branch gives financial assistance to landholders for the development and improvement of water supplies on agricultural and pastoral leases. Another function of the branch, which is increasing in importance as it builds up a body of technical data and information about the Territory's water resources, is the dissemination of this knowledge by the provision of advice and technical assistance to professional drillers and to landholders.

Underground water

The marked seasonal rainfall over the whole of the Northern Territory is one of the basic factors affecting the pastoral industry, which provides a large proportion of the Territory's income. Underground water supplies are of great importance in the Territory, where most of the cattle numbers are dependent on underground supplies for three to five months each year, because of the inadequacy of surface water during the dry season.

Rainfall is one of the factors controlling cattle numbers, but geological features, controlling both soils and the storage of underground water, are equally important. In the northern-most portion of the Territory, which receives from 25 to 60 inches of seasonal rainfall a year, surface water supplies are,

in general, adequate for the pastoral industry. Despite this, however, the area has a comparatively low carrying capacity for cattle, and the pastoral industry is concentrated more in inland areas where feed retains more nutritive value in winter, despite dry conditions. South from this well-watered northern-most portion, the Territory becomes progressively drier, with an average annual rainfall of only five inches at the margins of the Simpson Desert in the south-east corner. In the lower rainfall areas the search for potable underground water becomes exacting, but in the Ord-Victoria region and the Barkly Tablelands the best pastures are generally in areas where sub-surface conditions are suitable for the storage of underground water.

In the Ord-Victoria region the best grass lands overlie volcanic rocks and extend over some 10,000 square miles. Outcrops of sandstone, limestone and shale also occur in this area and underlie the volcanic rocks in most places. In general, these sedimentary rocks dip gently to the east, and sub-artesian conditions prevail. Underground water in this region is obtained from sandstone aquifers which yield supplies ranging up to 4,000 gallons an hour. Most of the bores are required in areas where the sediments are overlain by basalts; selection of bore sites is usually difficult. Supplies of shallow groundwater from joints, cracks and faults in the basalt are insignificant, and virtually all the bores obtain water from the sub-basalt sandstone aquifers. Successful bores in this area have ranged in depth from 200 feet to more than 900 feet. There are also small basins of younger sedimentary rocks in the region, some of which yield sub-artesian, and in places artesian, water and provide areas of good pastures.

The Barkly Tablelands, which extend into Western Queensland, overlie flat-lying limestone, sandstone and shale of the Barkly Basin. In most places underground water is under pressure but no flowing bores are known. Sandstones and beds of limestone with fractures and solution cavities provide a number of aquifers within the Basin. The hydraulic surface (to which pressure water will rise in bores) ranges between 500 and 600 feet above sea level, and adequate supplies for the watering of stock are available at depths ranging from 150 to 400 feet from the surface. The water from over 90 per cent of the bores is suitable for stock and over 50 per cent of it is suitable for human consumption. Investigations by the Commonwealth Bureau of Mineral Resources, Geology and Geophysics indicate that underground water supplies will be more than sufficient for the future development of the pastoral industry on the Tablelands.

In the Alice Springs district valuable pastures occur on a great variety of rock types, and from some of these very little underground water is available. Many shallow bores obtain water from alluvium near stream channels. There are also many successful bores in porous sands and limestone in Mesozoic and Cainozoic sedimentary basins and in some Upper Proterozoic and Palaeozoic limestones and sandstones. Small supplies of underground water are obtained from bores intersecting joint zones in metamorphic rocks and granite of Archaean age. However, except in areas close to recharge, the water quality varies from moderate to poor.

The Water Resources Branch of the Northern Territory Administration has intensified research aimed at increasing the water supplies for Alice Springs and Darwin. Bores into the Palaeozoic Mereenie sandstone, twelve miles south of Alice Springs, have intersected sub-artesian aquifers at depths between 500 and 1,000 feet, and water from these bores is now the main source for the town supply. Promising finds of water have also been made in the Ti Tree and Dulcie basins to the north of Alice Springs, with possible potential for irrigation use. Tennant Creek obtains its water supply from two small sedimentary basins located respectively nine miles and sixteen miles south of the town, known as the Cabbage Gum and Kelly Well basins, which currently supply more than 1,000,000 gallons per week to the town reticulation. High yielding dolomite aquifers of lower Proterozoic age in the area sixteen miles south of Darwin have been developed and are augmenting the Darwin water supply.

At 30 June 1967, 5,478 bores and wells were registered in the Territory. Of these, 3,504 were for pastoral use, 314 were for agricultural use, 388 served town and domestic water supplies, 34 were in use on mining fields, 621 were investigation bores, 403 were Government established stock route bores, and 214 were classified under other uses. These include successful bores which have collapsed, and bores which were unsuccessful owing to drilling difficulties, or to insufficient quantity or poor quality of underground water.

Irrigation

There are no large water conservation projects in the Territory with the exception of the Manton Dam (12,700 acre feet), which serves Darwin with a reticulated supply. Some water is drawn from the rising main between the Manton Dam and Darwin for irrigation purposes, but the trend is for properties in this area to develop their own water supplies, either by boring or by pumping from watercourses or lakes. Investigations for additional water to augment Darwin's water supply are proceeding on the Darwin River, and in the McMinns Lagoon area.

The hydrological investigations required in the Northern Territory as part of the National Water Resources Assessment Programme are being carried out by the Water Resources Branch. A network of bore gauging stations is being built and operated for this purpose, and the results will help development planning as well as providing data for environmental scientists. In particular areas of development where water supply or irrigation proposals require surface water data, supplementary gauging stations are being built to obtain this information. Since the start of stream-gauging activity in the Northern Territory the Water Resources Branch has established 273 gauging stations. As at 1 June 1967, the Northern Territory stream-gauging network comprised 191 operating stations; of these, 125 were base stations for measuring stream flow and 66 were supplementary stations.

Agricultural activity in the Territory is not extensive, being confined to the Darwin, Adelaide River, Coomalie Creek, Daly River, Katherine River, and Alice Springs areas, with only small acreages being utilised. In the Territory 45 licences to divert water from streams have been issued. The total licensed area for irrigation is 2,652 acres, but the actual area irrigated is less than this. There are also a number of farms irrigated from bore supplies, particularly in the Alice Springs area. Purposes for which irrigation water is used include the growing of fruit, vegetables, crops and pastures, and also dairying and mixed farming. Some 300 acres of irrigated rice were grown commercially on the Adelaide River in the 1964–65 season in a pilot farm project.

The Northern Territory Administration and the Commonwealth Scientific and Industrial Research Organization are investigating the potentialities of the Katherine area for agricultural production. In this area there are fifteen licensed stream diversions covering an area of 460 acres, and investigations are continuing into the possibility of using the Adelaide and Daly Rivers for irrigation. A dam site is under investigation at Adelaide River Township. The Daly River appears promising for irrigation purposes as it has a minimum dry season flow of 275 cusecs and a reliable annual flow, without regulation, of 300,000 acre feet. The mean annual flow of the river is more than 2,000,000 acre feet per year. Extensive surveys are being carried out on the coastal plains in the Daly area, including details of topography, hydrology, and soils. Surveys of a dam site at Nancar are being undertaken.

Papua and New Guinea

Rainfall in Papua and New Guinea varies considerably from approximately 240 inches near Lindenhafen (New Britain) and 230 inches at Kikori (Papua) to about 70 inches near Marienburg (New Guinea) and 40 inches at Port Moresby (Papua). For a general description of these territories *see* the chapter The Territories of Australia of this Year Book. Irrigation has not been developed on any organised basis owing to the availability of high rainfall and the nature of agricultural development.

The Territory of Papua and New Guinea is well served with large rivers deriving their water from heavy tropical rains and high mountains which rise to over 14,000 feet, but complete data regarding water resources are not available. During 1966–67 the Commonwealth Government continued to implement the policy of establishing a national network of stream-gauging stations which can be used in assessing the water resources of the Territory, while continuing to collect hydrological data for specified proposed hydro-electric projects.

The largest rivers in the Territory include the Fly (700 miles long, situated in the western division of Papua), the Sepik (700 miles), the Ramu (450 miles), the Purari (300 miles), and the Markham (110 miles). The main water conservation interest in New Guinea at present is the hydro-electric potential, which is extensive. An outline of schemes at present in operation is given in Chapter 27, Electric Power Generation and Distribution.

DROUGHTS IN AUSTRALIA*

Droughts

The following discussion of droughts in Australia is taken mainly from two Bureau of Meteorology publications: *Droughts in Australia*, by J. C. Foley (Bulletin No. 43, 1957); and *Rainfall Deciles as Drought Indicators*, by W. J. Gibbs and J. V. Maher (Bulletin No. 48, 1967). Droughts which were confined to comparatively small areas of Australia are not mentioned below but are treated in detail in these Bureau of Meteorology publications, which also give comprehensive rainfall data and detailed descriptions of data treatment and analysis methods.

What is drought?

There is no universally agreed definition of drought, but a definition which may be widely accepted is 'severe water shortage'. This definition begs the question somewhat, as it requires a further definition of 'shortage' or alternatively the specification of the amount of water needed. Water need depends on the types and numbers of animal and plant communities using the water, so that the concept of drought cannot be divorced from the use to which water is put.

Drought is in many ways a relative term. Crops, vegetation, industries, and land use in different parts of the world are more or less adjusted to the moisture or water normally available. A rainless period that would constitute a drought in one region may not be unusual or injurious in another. Drought is also a relative term in a given area, since conditions which a market gardener would regard as drought may cause a pastoralist no concern.

The vulnerability of a nation's economy to drought changes with time. Increased development, particularly in the spheres of transport and water conservation, and diversification of the economy may mitigate the serious adverse effects of extended dry periods which in earlier years would have been regarded as disastrous.

Development does not always act to decrease the effects of drought. Population increases and the establishment of secondary industries create an increased water need and give rise to problems of combating drought in new areas and sectors of the economy.

Water need is thus a function of time and place and depends on many factors. The nature and intensity of land and water use, transport facilities, water storage capacity, number of stock involved, and the development of drought resistance in plants are among the factors which affect water need and the impact of drought on primary and secondary industry and the community in general. The only objective method of defining drought is to specify minimum water needs for a particular purpose and this can then be compared with water available.

Rainfall as a drought index

The natural availability of water depends on rainfall, although other effects such as evaporation, wasteful use of water, moisture storage in the soil, and storage of water in artesian basins or reservoirs must be taken into account. Nevertheless rainfall is the best single index of water availability and monthly rainfall totals are sufficient for most studies of the occurrence, spread, and breaking of droughts.

Thus, if the minimum water need for a given period of time is met by rainfall of a given amount 'x', drought may be said to occur whenever the rainfall during that time interval is less than 'x', and the severity of drought linked to the amount by which rainfall falls short of the requirement.

Rainfall has several advantages over other criteria, such as the effects on plants and animals, as a basis for study. Rainfall data are numerical, and methods for their observation, collection, and processing have been substantially unchanged over the past 100 years. The data are therefore amenable to statistical analysis by electronic computers. They also provide uniformity, reliability, and completeness of statistics to a degree that is impossible to obtain if other criteria are used as a basis for study.

Effective comparisons, based on rainfall data, can be made between droughts occurring at various stages in the development of the Australian economy, and meaningful conclusions can be drawn regarding the probability of future drought occurrence, severity, and extent.

Rainfall records are available for more than 10,000 stations in Australia, of which about 7,000 are currently in operation. The length of record varies greatly; at some stations records have been taken for more than 100 years and fifty per cent of stations have records exceeding 70 years.

* The following article on Droughts in Australia was specially prepared for this issue of the Year Book by the Director of the Commonwealth Bureau of Meteorology.

Drought study

Scientific study of the areal extent of drought and its frequency of occurrence is essential for the proper planning of agricultural, pastoral, industrial, and economic activities. Such studies can provide an assessment of drought risk and assist the planning of short-term action (such as declaration of drought occurrence and choice of areas to which stock might be moved).

An additional, useful field of research is the determination of the water needs of crops, animals, industry, and communities. This information is basic to any drought study and is essential if drought is to be defined in a meaningful way.

Surveys of the impact of drought on the Australian economy at various stages of its development are not only of historical interest. They provide information which can enable planners to profit from past experience and to seek remedies for circumstances which aggravated the disastrous effects of previous droughts.

Foley (1957) used reports of conditions of crops and livestock published in official bulletins, journals, and newspapers, together with rainfall analyses, to produce a comprehensive historical review of Australian rainfall and the effects of drought on primary industry. This work has been continued by other workers in the Bureau of Meteorology. The Bureau bases its current drought research programme on the statistical analysis of rainfall, but this has not been done to the exclusion of other factors significant in drought analysis and study.

Drought prediction

For many years there has been great interest in the variations of rainfall in time. Investigators have sought for any regularly recurring cycles of rainfall patterns, and for any tendency for dry and wet periods to persist. However, as yet no reliable method for the long-range forecasting of rainfall and drought has been devised.

Many writers have reported cycles with various periods, but their conclusions have been unable to withstand the test of critical statistical analysis. Further studies in this direction are planned by the Bureau of Meteorology, concentrating on very low rainfalls and using the latest statistical techniques combined with the calculation and analysis facilities of large, high-speed computers.

There have been numerous studies of persistence effects in meteorology. Maher (1966) has found a persistence effect, which is statistically significant, in day to day rainfall at a number of Australian rainfall stations. An examination of the records of thirty-one stations led him to conclude that the average lengths of run of monthly rainfall equal to or less than the median value were significantly greater than would be expected in a random series.

Treatment of data

Rainfall, unlike many other meteorological elements such as temperature and pressure, is non-continuous in time and space. As a result the statistical description of rainfall occurrence is quite complex.

The best known and most commonly used rainfall statistic is the arithmetic mean (often called the 'average' or 'normal'). Monthly means are computed by adding the rainfalls in a given month over a long period and dividing the total by the number of years of record.

Another statistic is the 'median' or '50 per cent' value, which is the value exceeded by half the occurrences and not exceeded by the other half. With many meteorological quantities the mean or median values are equal or very close, and the use of 'average' for either value causes no confusion. Although this is often the case with annual rainfall, for shorter periods (three months or less) the mean can differ significantly from the median.

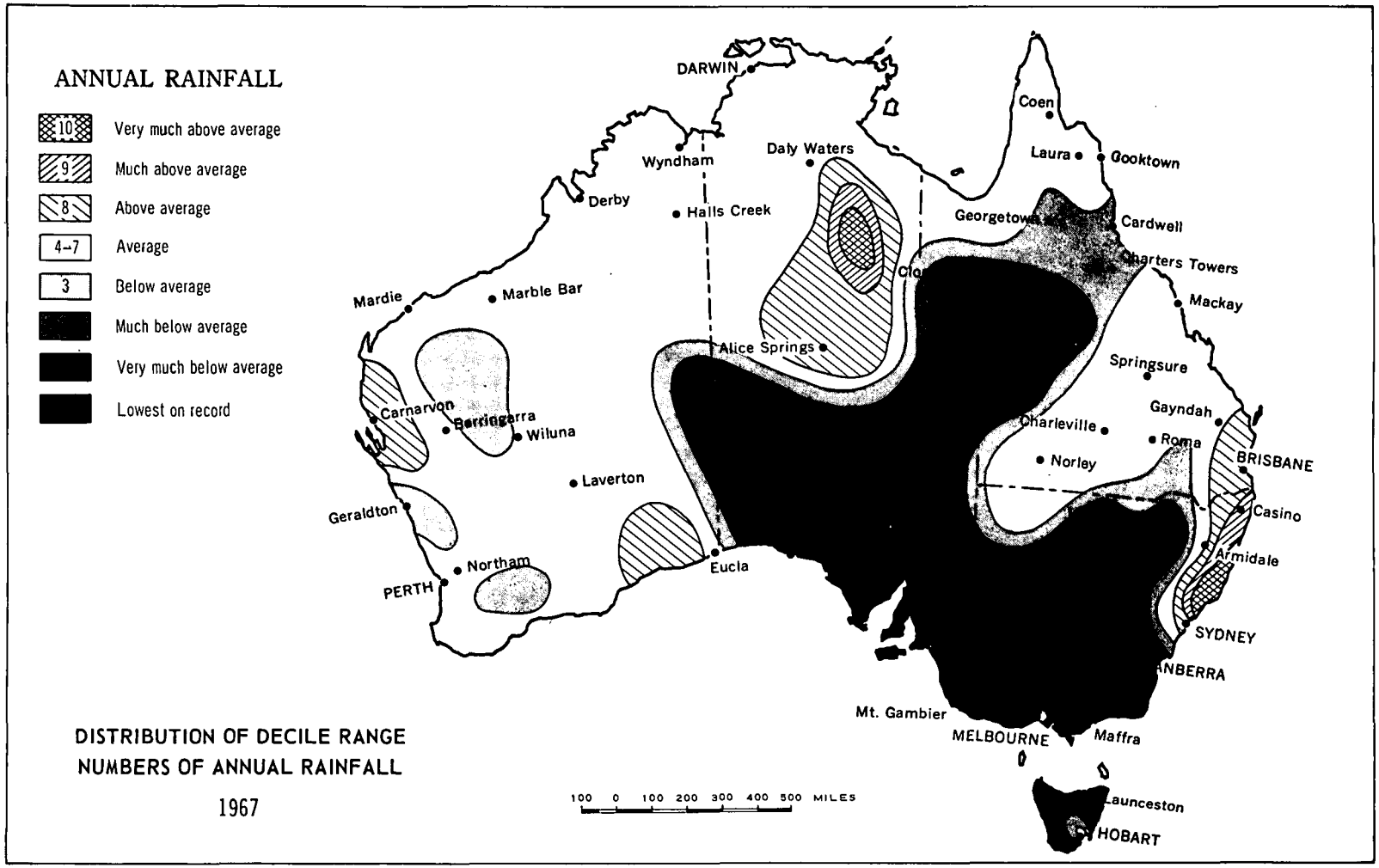
This is exemplified by January rainfalls for Sydney, Melbourne and Alice Springs, and July rainfall for Halls Creek.

MONTHLY RAINFALLS

(Inches)

Place	*Month*	*Mean*	*Median*
Sydney	January	3.73	2.78
Melbourne	January	1.89	1.43
Alice Springs	January	1.54	0.61
Halls Creek	July	0.25	Nil

PLATE 59


ANNUAL RAINFALL
10 Very much above average
9 Much above average
8 Above average
4–7 Average
3 Below average
Much below average
Very much below average
Lowest on record
DARWIN
Wyndham
Daly Waters
Derby
Halls Creek
Coen
Laura
Cooktown
Georgetown
Cardwell
Charters Towers
Mackay
Mardie
Marble Bar
Alice Springs
Springsure
Carnarvon
Barringarra
Wiluna
Charleville
Gayndah
Roma
Norley
BRISBANE
Laverton
Geraldton
Casino
Armidale
Northam
PERTH
Eucla
SYDNEY
Mt. Gambier
MELBOURNE
Maffra
Launceston
HOBART
100 0 100 200 300 400 500 MILES
DISTRIBUTION OF DECILE RANGE
NUMBERS OF ANNUAL RAINFALL
1967

In these cases the mean value is not the same as the median value. At Alice Springs the January mean of 1.54 inches is equalled or exceeded in only about 35 per cent of years, and at Halls Creek the July mean of 0.25 inches is equalled or exceeded in about 20 per cent of years. In fact, at Halls Creek July rainfall is nil in almost 70 per cent of years, although the mean is 0.25 inches. For this reason it is preferable to describe monthly, and longer periods up to annual, rainfalls by the median or 50 per cent value rather than the mean.

To obtain some idea of the 'spread' or variability of monthly rainfall, the amount which is not exceeded in the driest 10 per cent of years (the first decile) and that exceeded in the wettest 10 per cent of years (the ninth decile) are often quoted.

Decile values divide each 10 per cent of occurrences from the driest to the wettest years and give some indication of rainfall variability. The Bureau of Meteorology has adopted decile ranges for drought studies. The first decile range (decile range 1) is the range of the driest 10 per cent of rainfalls, the second decile range is the next driest 10 per cent and so on. The middle 40 per cent of rainfalls (decile ranges 4–7) can be considered as 'average', although in some cases the arithmetic mean may lie outside this range.

Decile maps

Maps for each year from 1885 to 1965 showing the decile ranges in which annual rainfall occurred are given in *Rainfall Deciles as Drought Indicators*, together with maps showing the rainfall amount corresponding to the first, fifth and ninth deciles. The yearly maps show a measure of rainfall anomaly rather than the actual amount of rainfall and this assists rapid assessment of the rainfall situation over areas where the mean and median amounts of rainfall differ greatly. The map opposite showing the distribution of decile range numbers of 1967 annual rainfall is an example of a decile map.

The following terminology is used in this map and in Bureau of Meteorology publications such as the *Monthly Rainfall Review*, *Seasonal Summary* and *Statement on Drought*.

Extent of range	*Formal title*	*Descriptive name*
Lowest 10 per cent of monthly rainfalls	Decile range 1	Very much below 'average'
Next lowest 10 per cent	Decile range 2	Much below 'average'
Next lowest 10 per cent	Decile range 3	Below 'average'
Middle 40 per cent of monthly rainfalls	Decile ranges 4–7	'Average'
Next higher 10 per cent	Decile range 8	Above 'average'
Next higher 10 per cent	Decile range 9	Much above 'average'
Highest 10 per cent of monthly rainfalls	Decile range 10	Very much above 'average'

The map opposite clearly depicts abnormally low rainfalls during 1967 over South Australia, Victoria, south-western Queensland, and much of Tasmania and New South Wales. The 1967 annual rainfall was lower than any annual total previously recorded at most observing stations in the area described as 'lowest on record' in the map. Considered in combination with similar maps for previous years, this map provides an indication of the extent and severity of drought in 1967.

Assessment of drought areas

Areas on annual decile maps where rainfalls were in the first decile range can be used as an arbitrary and approximate assessment of drought areas, although this index has the following limitations:

(*a*) rainfall totals are for calendar years, and droughts occur over periods lasting from one month to a number of years;

(*b*) in the northern half of Australia the 'water year' does not coincide with the calendar year; and

(*c*) drought occurrence depends on land use as well as rainfall.

This index of drought gives a good correspondence with the occurrence of major droughts as given by Foley (1957) and based on newspaper and other reports as well as rainfall statistics. However, *the index gives only an approximate indication of drought risk and the manner in which drought areas cover the continent.* In some areas drought may occur or continue with rainfall in the second, third, or higher decile ranges.

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Drought frequency

Two of the conclusions reached by Gibbs and Maher from their study of rainfall decile maps were as follows.

(*a*) It is most unlikely that the whole of the Australian continent will ever be drought-affected at any one time.

(*b*) If 'drought' is defined as the occurrence of a year with rainfall in the first decile range, then for 20 years in every 100 the whole of Australia is likely to be free of major droughts. The frequency of completely 'drought' free conditions in a given State might be expected to range from 46 in 100 years in Western Australia to 74 in 100 in Tasmania. 'Drought' affecting half the Australian continent might be expected twice in 100 years.

History of drought in Australia to 1957

Foley (1957) used reports of conditions of crops and livestock, published in official bulletins or in newspapers, together with rainfall analyses to determine the history of drought in Australia. Foley gives a comprehensive review for each Australian State and a briefer discussion for the Commonwealth as a whole. A summary taken from Foley's review is given by Gibbs and Maher (1967) and supplemented by later reports for the period 1955 to 1966. Readers interested in the detailed history of drought in Australia are referred to these works. An earlier account of droughts in Australia, derived from Foley's review, will be found in a special article in Year Book No. 45, pages 51–6.

The following list of widespread droughts experienced in Australia since rainfall records commenced is taken from Foley's review. The drought period 1958 to 1968, too recent to be included by Foley, has been treated separately because of its topical interest.

MAJOR DROUGHTS TO 1957, AND REGIONS MAINLY AFFECTED

1864 to 1866 (or 1868) — The little data available indicate that this drought was rather severe in Victoria, South Australia, New South Wales, and Queensland, and also in Western Australia.

1880 to 1886 — Victoria (north and Gippsland), New South Wales (mainly northern wheat belt, northern tablelands and south coast), Queensland (1881 to 1886 in south-east with breaks, otherwise mainly in coastal areas, the central highlands and central interior in 1883 to 1886), and South Australia (1884 to 1886 mainly in agricultural areas).

1888 — Victoria (north and Gippsland), Tasmania (1887 to 1889 in the south), New South Wales, Queensland (1888 to 1889), South Australia, Western Australia (central agricultural areas).

1895 to 1903 — Practically the whole of Australia, but most persistent on the coast of Queensland, in inland areas of New South Wales, in South Australia, and in central Australia.

This was the most widespread and severe drought in the history of Australia. Sheep numbers which had reached more than 100 million were reduced by approximately half and cattle numbers by more than 40 per cent. Average wheat yields exceeded 8 bushels per acre in only one year of the nine and dropped to 2.4 bushels per acre in 1902.

1911 to 1916 — Victoria (1913 to 1915 in north and west), Tasmania (1913 to 1915), New South Wales, particularly inland areas, Queensland, Northern Territory (mainly in the Tennant Creek–Alexandria Downs area), South Australia (some breaks in agricultural areas), and Western Australia (1910 to 1914).

1918 to 1920 — Queensland, New South Wales, South Australia, Northern Territory (Darwin–Daly Waters area and central Australia), Western Australia (Fortescue area), Victoria, and Tasmania.

1939 to 1945 — New South Wales (severe on the coast), South Australia (persistent in pastoral areas), Queensland, Tasmania, also (more particularly in 1940 and 1944 to 1945) in Western Australia, Victoria, and central Australia, Tennant Creek–Alexandria Downs area in 1943 to 1945.

DROUGHTS OF A LESSER DEGREE OF SEVERITY, AND AREAS AFFECTED

1922 to 1923 and 1926 to 1929	Queensland (severe), New South Wales (intermittent), Western Australia (more particularly Fortescue—1922 to 1929), South Australia (mainly pastoral areas), central Australia (1924 to 1929), Northern Territory (1926 to 1929), Victoria (1925 to 1927, severe in the north 1925 to 1929), Tasmania (1925 to 1927, not continuous).
1935 to 1938	Western Australia (severe in pastoral and northern agricultural areas), Queensland (breaks on the coast), Victoria (north and Gippsland), New South Wales (not continuous except on the northern tablelands), Northern Territory, South Australia (1935 to 1936 in pastoral areas and 1938 in agricultural areas), Northern Tasmania (1935 to 1937, not continuous).
1946 to 1949	Queensland (central coast and highlands and central interior, elsewhere mainly in 1946), Northern Territory, New South Wales (mainly in 1946 to 1947), Western Australia (more particularly in central agricultural areas in 1947 to 1950), and northern Tasmania (1948 to 1949).
1951 to 1952	Queensland and Northern Territory, Western Australia, especially pastoral areas (1951 to 1954).

Drought period 1958 to 1968

This drought was one of the most widespread in recorded Australian history and probably second only to the 1895 to 1903 drought in severity.

For more than a decade from 1957, drought was consistently in the news and frequently made headlines from 1964 onwards. This is treated as one major drought period here, but could, perhaps, be subdivided into two which overlapped, both in time and area. Central Australia and vast areas of adjacent Queensland, South Australia, Western Australia, New South Wales, and northern Australia were affected, with varying intensity, between 1957 and 1966, and south-eastern Australia experienced a severe drought between 1964 and 1968.

Rainfall deficits were not serious in the Northern Territory in 1957, but the failure of rains in 1958 led to widespread drought, which also extended to the Kimberley districts of Western Australia. The position was aggravated by a very dry year in 1961, by which time the drought had extended over the greater part of the continent. Further extended dry periods, culminating in abnormally low rainfalls in 1964 to 1966, over central Australia and parts of New South Wales and Queensland, produced one of the most severe droughts recorded in 170 years of European settlement in Australia.

Crops and pastures failed, sheep and cattle numbers were heavily reduced, and water storages, particularly in New South Wales, were so reduced that irrigation had to be restricted.

Rains in 1966 broke the drought in central Australia, and the position also improved over much of South Australia and New South Wales during 1966, but deteriorated again in 1967.

South Australia had experienced drought of varying severity from 1957, but Victoria was relatively unaffected until 1965. However, by the end of 1967 sustained dry weather had produced an extremely severe drought over southern and western parts of New South Wales, and most of South Australia, Tasmania, Victoria, and south-western Queensland. The map facing page 993 gives a good indication of the area affected. The 1967 rainfall at many places in south-eastern Australia was the lowest annual rainfall on record.

The serious adverse effects on primary industry produced by this drought were in many ways similar to those produced by others listed on page 994; however, several factors combined to reduce the economic loss in the pastoral sphere. The most significant of these were the greatly reduced numbers of rabbits compared with earlier years, the availability of transport which facilitated fodder supply and permitted a form of nomadic grazing, and the increased meat-work activities during the period.

However, attention was focused on the vulnerability to drought of irrigation areas, secondary industries, and centres of population. Water storages and river flows dropped to very low levels, in some cases the lowest on record, resulting in restrictions on the use of water which affected irrigation supplies and some spheres of secondary industry. Water consumption was also heavily restricted at some centres, including Canberra and the Melbourne metropolitan area. Resulting side effects on small businesses and industries were numerous and far reaching.

Excellent rain in the autumn of 1968 brought the drought over south-eastern Australia to an end in most respects. The autumn rain did not, however, replenish the depleted water storages sufficiently to provide satisfactorily against an early return of dry weather. This illustrates the fact that the 'break' of a drought is as difficult to define as drought itself, since the amount of water necessary to enable pastures to recover after a long drought may be very different from that required to provide satisfactory storage for irrigation, industrial, and other consumer needs.

Conclusions

The history of drought in Australia reveals that during the last 100 years there have been at least eight major droughts affecting the greater part of the continent and several other droughts causing severe losses in restricted areas. The droughts of 1895 to 1903 and 1958 to 1968 were the most disastrous in their effects on primary production.

Large and irregular variations in rainfall will continue to occur in Australia, and it is quite possible that rainfall deficiencies at some time in the future will exceed any experienced in the last 100 years.

Drought studies and forecasting research are continuing. These will facilitate the planning of measures to combat the effects of drought, but there is no immediate prospect of reliable long term prediction of rainfall.

Drought is part of the Australian scene, and it will continue to be necessary to study and implement measures to counteract its adverse effects and reduce the vulnerability of the economy. These measures include the conservation of fodder and water, the provision of adequate transport facilities for removal of stock, the supply of fodder and water to drought stricken areas, and research in many fields related to water, land, and fodder use.

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