CHAPTER SIXTEEN

WATER RESOURCES

This chapter is divided into two major parts—existing water resources in Australia and the management of these resources. The former provides information on such topics as the geographic background to water resources, surface and groundwater supplies and use, and the drainage divisions in Australia. The latter summarises Australian and State assessment and management of water resources.

For information concerning general, descriptive and historical matter *see Year Book* No. 37, pages 1096–1141 and *Year Book* No. 51, pages 228–31. A special article on drought in Australia, contributed by the National Climate Centre, is included at the end of the chapter.

Introduction

Rainfall, or the lack of it, is the most important single factor determining land use and rural production in Australia. Chapter 5, Physical Geography and Climate of Australia contains details on geographical and climatic features that determine the Australian water pattern. The scarcity of both surface and groundwater resources, together with the low rates of precipitation which restrict agriculture (quite apart from economic factors), has led to extensive programs to regulate supplies by construction of dams, reservoirs, large tanks and other storages.

Geographic background

General

Water resources are determined by rainfall, evaporation and physical features including soil, vegetation and geology. Chapter 5, Physical Geography and Climate of Australia, contains a detailed description of the climatic features of the country. A brief description of the landforms appears in *Year Book* No. 61, pages 25–27. In assessing Australia's water resources, dependability and quality of supply must be considered, as well as quantity.

Topography

The major topographical feature affecting the rainfall and drainage patterns in Australia is the absence of high mountain barriers. Australia's topographical features range from sloping tablelands and uplands along the east coast Main Divide, through the low plain and marked depression in the interior to the Great Western Plateau.

Drainage

Only one-third of the Australian land mass drains directly to the ocean, mainly on the coastal side of the Main Divide and inland with the Murray–Darling system. With the exception of the latter, most rivers draining to the ocean are comparatively short but account for the majority of the country's average annual discharge. Surface drainage is totally absent from some arid areas of low relief.

Climate

Australia's large area (7.7 million square kilometres) and latitudinal range (3,700 kilometres) have resulted in climatic conditions ranging from alpine to tropical. Two-thirds of the continent is arid or semi-arid, although good rainfalls (over 800 mm annually) occur in the northern monsoonal belt under the influence of the Australian–Asian monsoon, and along the eastern and southern highland regions under the influence of the great atmospheric depressions of the Southern Ocean. The effectiveness of the rainfall is greatly reduced by marked alternation of wet and dry seasons, unreliability from year to year, high temperatures and high potential evaporation.

Settlement

The availability of water resources controls, to a large degree, the possibility and density of settlement; this in turn, influences the quality of the water through production and disposal of waste. Most early settlements were established on the basis of reliable surface water supplies and, as a result, Australia's population is concentrated along the coast, mainly in the comparatively fertile, well-watered east, south-east and far south-west.

As settlement spread into the dry inland grazing country, the value of reliable supplies of underground water was realised. Observations of the disappearance of large quantities of the rainfall precipitated on the coastal ranges of eastern Australia eventually led to the discovery of the Great Artesian Basin which has become a major asset to the pastoral industry. Development, however, has not been without costs. Significant environmental degradation and deterioration in water quality are becoming evident.

For further information on the influence of water resources on the spread of settlement in Australia *see Year Book* No. 61, page 860.

In the text and tables below, water volume, usage and flow are shown in litres rather than in cubic metres as in earlier issues. Equivalence and terms used are:

(KL) Kilolitres= 1.00 x 10^3 litres (1 cubic metre)
(ML) Megalitres= 1.00 x 10^6 litres
(GL) Gigalitres= 1.00 x 10^9 litres
(TL) Teralitres= 1.00 x 10^{12} litres

Surface supplies

Distribution and volume

As described above, permanent rivers and streams flow in only a small part of the continent. The average annual discharge of Australian rivers has been recently assessed at 398 teralitres (TL) of which 100 TL is now estimated to be exploitable for use on a sustained yield basis. This is small in comparison with river flows on other continents. In addition, there is a pronounced concentration of runoff in the summer months in northern Australia while the southern part of the continent has a distinct, if somewhat less marked, winter maximum.

Variability of flow

Even in areas of high rainfall, large variability in flow means that, for local regional development, most streams must be regulated by surface storage. However, in many areas evaporation is so great that storage costs are high in terms of yield. Extreme floods also add greatly to the cost of water storage, because of the need for adequate spillway capacity.

Potential development

Some 83 per cent of all water used in Australia is surface water. This quantity is about 21.5 TL a year and represents about 21 per cent of the possible usable surface water available in Australia; it does not include the amount diverted for hydro-electric power generation and other instream purposes which does not affect the quantity of water available. However, the great variability of river discharge, high evaporation, lack of sites for storage on many catchments, and economic considerations limit potential development. There is, however, considerable scope for greater efficiency in water use.

Groundwater supplies

About 80 per cent of Australia is significantly dependent on groundwater supplies. Australia's estimated sustainable groundwater yield is 72 TL, and annual groundwater usage is estimated at about 2.2 TL.

Groundwater is divided according to its occurrence in the three main classes of aquifer:

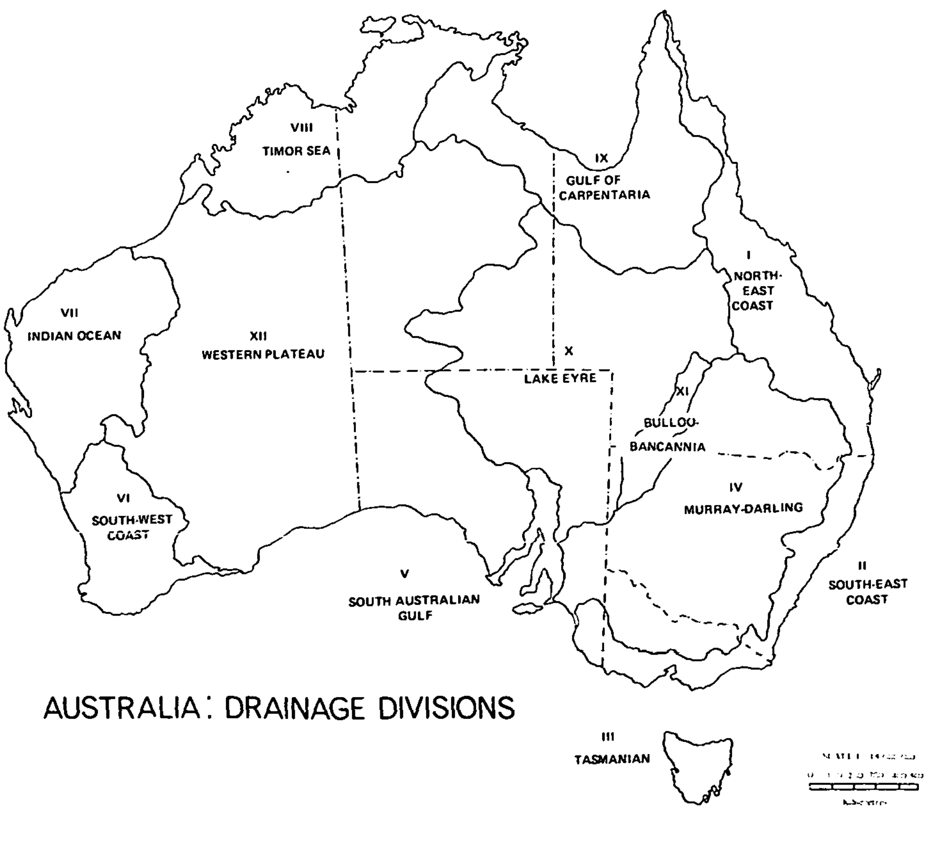
(i) **Shallow unconsolidated sediments** comprise alluvial sediments in river valleys, deltas and basins; aeolian (windblown) sediments which generally occur in coastal areas; and lacustrine (lake) sediments. These sediments are often highly permeable and porous. Permeability and porosity may vary markedly according to orientation. Unconsolidated aquifers of this group generally occur at depths of less than 150 metres and are often readily accessible to sources of water for recharge. Marked seasonal variations in water level are common.

(ii) **Sedimentary rocks** are generally made up of consolidated sediments. The aquifers owe their porosity to small voids between the grains which are often well compacted and cemented. They often cover significant areas, being continuous and of appreciable thickness. Rock strata usually dip quite gently. Nevertheless, over the full extent of the larger sedimentary basins, aquifers may reach great depths. Areas where recharge takes place may be small in relation to the extent of the aquifers. Water quality in individual aquifers may be quite good and fairly uniform over large areas. Some sediments contain a number of permeable and impermeable layers, creating a vertical sequence of separate aquifers, and water quality may vary greatly between them.

(iii) **Fractured rocks** comprise hard igneous and metamorphosed rocks which have been subjected to disturbance and deformation. Aquifers resulting from the weathering of any rock type are also included in this group. Water is transmitted mainly through joints, bedding planes, faults, caverns, solution cavities and other spaces in the rock mass.

The quality of groundwater varies considerably and sources are subject to pollution in much the same way as surface supplies. As a general rule, groundwater from shallow unconsolidated sediments is of good quality but there are instances where groundwater has been polluted, particularly around major urban centres, by sewerage effluent, drainage from refuse tips and from specific industrial pollutants. Supplies from sedimentary basins and fractured rocks are more variable in both quality and quantity, especially in the more arid regions of the continent. High nitrate concentrations tend to be a common occurrence in groundwaters in northern and central Australia.

Drainage divisions and the use of surface and groundwaters



AUSTRALIA: DRAINAGE DIVISIONS

To promote a unified approach, river basins or groups of river basins have been adopted as the primary units of assessment. The *Review of Australia's Water Resources 1975* (Department of National Development and Energy, Australian Water Resources Council, Canberra) contains a summary of the 244 river basins grouped into twelve divisions, together with a map showing the divisions. (*See* above.)

The conjunctive approach to water resources, even to importing water from outside the region, generally makes more water available for use than would be the case with independent use of the various sources. *Year Book* No. 61, pages 867–8 contains details of the conjunctive use of surface and groundwaters.

The second national survey of water use, *1985 Review of Australia's Water Resources and Water Use*, has been conducted by the Australian Water Resources Council. The exploitable yield of surface water for each river basin (aggregating to drainage divisions) was reassessed. The estimates do not take into account the economic potential or value of the diverted water, or the desirability of developing the resource. They represent the volume of water able to be diverted on a regular basis into conventional water supply systems or to substantial private use, utilising existing storages and potential dam sites.

SURFACE WATER: ESTIMATES OF MEAN RUNOFF, TOTAL POSSIBLE EXPLOITABLE YIELD AND CURRENT USE BY DRAINAGE DIVISIONS
(*Source:* Australian Water Resources Council, 1985)

		Surface water (teralitres per annum)			
Drainage division		*Mean runoff*	*Total possible exploitable yield(a)*	*Use(b)*	*Use as percentage of exploitable yield(%)*
I	North-East Coast	84	23	3.5	15
II	South-East Coast	42	15	4.3	28
III	Tasmania	53	11	1	9
IV	Murray-Darling	25	12	10	81
V	South Australian Gulf	1	0.3	0.1	44
VI	South-West Coast	7	3	0.4	13
VII	Indian Ocean	4	0.3	n.s.	9
VIII	Timor Sea	81	22	2	9
IX	Gulf of Carpentaria	93	13	0.1	1
X	Lake Eyre	6	0.2	n.s.	13
XI	Bulloo-Bancannia	1	n.s.	n.s.	—
XII	Western Plateau	2	0.1	n.s.	—
Australia	. . . .	**398**	**100.0**	**21.5**	**21**

(*a*) Exploitable yield is estimated total divertible fresh and marginal water taking account of technical factors but not economic, environmental or social constraints. (*b*) Urban, industrial and agricultural uses of water only. In-stream uses such as hydro-electric generation are not included.
NOTE: n.s.—not significant.

Water quality

The quality of surface water in Australia varies greatly and is controlled by climate, geology, stream flow rates, biological activity and land use. Most of the variability is related to water events such as storm flows, floods and drought. Water pollution is generally at a low level compared to other similarly developed countries. The great majority of Australians enjoy domestic, irrigation and recreational waters of good to excellent quality.

Very little is known of the water quality conditions which prevailed prior to European settlement and development in Australia. It is therefore difficult to judge the full impact of urban, agricultural, industrial and mining developments, and the effects that water resource development measures, such as large dams, have had on the quality of the resource. Levels of toxic pollutants have undoubtedly increased, as have the salt and sediment loads of the rivers. While water quality would, at times, have been poor prior to settlement, levels are believed to have generally declined. On the other hand, regulation of major rivers has reduced some of the impacts of floods and droughts.

An increasing appreciation of water quality in recent times has led to improved management. Measurable improvements in water quality over the last decade have resulted from pollution controls in industry and mining, and more effective sewerage treatment. Means of control of pollution from widespread agricultural activity such as problems of salinity and turbidity, are under development.

The major water quality issues and problems faced in Australia are salinity, turbidity, excessive plant and algal growths (eutrophication), and water treatment for small community water supplies. There is also a scarcity of data, information and research on some aspects of water quality and the protection of aquatic species and habitats. Many of the severe pollution problems found in other countries have been avoided in Australia, because of the general absence of highly polluting industries and the location of major cities on or near the coastline enabling ocean disposal of wastes.

Groundwater is an important substitute for surface water in many parts of the country such as in the arid interior where the Great Artesian Basin provides the only reliable continuous supply of water for stock and domestic purposes. This Basin underlies 23 per cent of the continent but the high ratio of sodium to calcium and magnesium ions has an adverse effect on soil structure, rendering it impervious and generally unsuitable for irrigation.

Groundwater is increasing in importance as a source of water for irrigation, industry and domestic supply. Following measurements taken in 1983-84, divertible resources and abstraction of groundwaters in the twelve drainage divisions are shown below.

GROUNDWATER ESTIMATES OF DIVERTIBLE RESOURCES AND ABSTRACTION BY DRAINAGE DIVISIONS, 1983-84

(*Source:* Australian Water Resources Council, 1985)

Drainage division		*Groundwater (teralitres per annum)* — *Divertible groundwater resources (a)*	*Abstraction during 1983-84*	*Abstraction as percentage of divertible groundwater (%)*
I	North-East Coast	2	0.5	29
II	South-East Coast	2	0.4	23
III	Tasmania	0.1	n.s.	—
IV	Murray-Darling	2	0.5	22
V	South Australian Gulf	0.1	n.s.	68
VI	South-West Coast	1	0.3	24
VII	Indian Ocean	0.5	0.1	10
VIII	Timor Sea	3	n.s.	0.5
IX	Gulf of Carpentaria	2	0.1	5
X	Lake Eyre	0.6	0.2	31
XI	Bulloo-Bancannia	0.1	n.s.	—
XII	Western Plateau	1	n.s.	—
Australia		**14.5**	**2.2**	**15**

(a) The divertible groundwater resource is the volume of water that can be withdrawn from an aquifer on a sustained basis without depleting the storage; however in practical operation of many groundwater storages 'sustained basis' may mean about 30 years or so, rather than indefinitely.

NOTE: n.s. = not significant

Increasing use is made of conjunctive schemes, for example, where groundwater supplies are tapped to augment surface water or where, as in the Burdekin Delta, groundwater aquifers are artificially recharged during the summer wet season to enable water to be stored at low cost with negligible evaporation.

Total water use or gross water consumed is the water supplied that is not returned to a stream or body of fresh water or diverted for use a second time. The total water use from 1 July 1983 to 30 June 1984 has been estimated to be 14,629 GL corresponding to an overall per capita use of 2,600 litres per day. Of this total, approximately 70 per cent was for irrigation, 21 per cent was for urban/industrial uses and 9 per cent was for other rural water use. Withdrawals for hydro-electric power have not been included. In terms of sources for the water used, by far the largest proportion (over 80 per cent) of water is drawn from surface water. Groundwater sources, although of importance in some regions, account for only a minor percentage of the water used.

PURPOSES OF WATER USE, 1983–84
(Gigalitres)
(*Source*: Australian Water Resources Council, 1985)

	Irrigation				*Urban/Industrial*					
Drainage division	*Pasture*	*Crops*	*Horti-culture*	*Total*	*Domestic*	*Indus-trial*	*Com-mercial*	*Total*	*Rural*	*Total use*
North-East Coast	70	803	92	966	353	147	41	542	149	1,657
South-East Coast	711	137	176	1,024	747	385	228	1,360	144	2,528
Tasmania	46	47	4	97	33	23	10	66	11	174
Murray-Darling	4,120	2,436	1,088	7,644	225	55	47	327	683	8,655
South Australian Gulf	28	2	45	76	141	24	34	198	38	312
South-West Coast	168	23	75	266	211	74	97	382	30	678
Indian Ocean	ns	2	7	9	24	17	6	48	8	64
Timor Sea	20	46	5	70	23	12	6	42	16	128
Gulf of Carpentaria	17	45	13	74	15	38	4	57	113	244
Lake Eyre	—	—	—	—	10	4	5	19	113	131
Bulloo-Bancannia	—	—	—	—	n.s.	n.s.	—	n.s.	18	18
Western Plateau	—	n.s.	n.s.	n.s.	9	9	3	21	19	41
Australia	**5,180**	**3,541**	**1,505**	**10,226**	**1,791**	**790**	**481**	**3,062**	**1,342**	**14,629**

NOTE: n.s. = not significant.

Major dams and reservoirs

A *Register of Large Dams in Australia* was published by the Australian National Committee on Large Dams in December 1982. The publication included, in chronological order, all large dams completed or under construction up to December 1982. In the list below, only dams with a gross reservoir capacity of more than 100 GL have been included. The list is based on the above publication and supplementary data for the latest years.

MAJOR DAMS AND RESERVOIRS IN AUSTRALIA

Name and year of completion	*Location*	*Gross capacity (gigalitres) (a)*	*Height of wall (metres) (b)*	*Purpose*
	NEW SOUTH WALES			
Eucumbene (1958)	Eucumbene River	4,798	116	H/E, IR, R, U
Hume (1936, 1961)	Murray River, near Albury	3,038	51	H/E, IR, R, U
Warragamba (1960)	Warragamba River	2,057	137	H/E, U
Menindee Lakes (1960)	Darling River, near Menindee	1,794	18	IR, R, U
Burrendong (1967)	Macquarie River, near Wellington	1,678	76	F/C, IR, R, U
Blowering (1968)	Tumut River	1,628	112	H/E, IR, R
Copeton (1976)	Gwydir River	1,364	113	IR, R, U
Wyangala (1936, 1971)	Lachlan River	1,220	85	IR, R
Burrinjuck (1927, 1956)	Murrumbidgee River	1,026	79	IR, R
Talbingo (1971)	Tumut River	921	162	H/E, IR,R,U
Glenbawn Dam (1958, 1987)	Hunter River, near Scone	870	100	F/C, IN, IR, R, U
Jindabyne (1967)	Snowy River	688	72	H/E, IR, R, U
Lake Victoria (1928)	Murray River, near S.A. border	680	-	IR, R, U
Keepit (1960)	Namoi River, near Tamworth	423	55	F/C, IR, U
Split Rock (1986)	Manilla River, Namoi Valley	370	64	IR
Windamere (1984)	Cudgegong River, near Mudgee	368	69	IR
Glennies Creek (1983)	Hunter Valley, near Singleton	284	65	IN, IR, R, U
Tantangara (1960)	Murrumbidgee River	254	45	H/E, IR, R, U
Avon (1927)	Avon River	214	72	U
Mangrove Creek (1983)	Mangrove Creek, near Gosford	170	80	U
Grahamstown (1969)	Grahamstown, near Newcastle	153	12	IN, U
Lake Brewster (1952)	Lachlan River, near Hillston	150	-	IR, R
Liddell (1968)	Gardiner Creek, near Muswellbrook	148	43	IN
Tallowa (1977)	Shoalhaven River, near Nowra	115	43	U
Googong (1978)	Queanbeyan River	125	62	U, F/C

MAJOR DAMS AND RESERVOIRS IN AUSTRALIA—*continued*

Name and year of completion	*Location*	*Gross capacity (gigalitres) (a)*	*Height of wall (metres) (b)*	*Purpose*
	VICTORIA			
Dartmouth (1979)	Mitta Mitta River	4,000	180	F/C, H/E, IN, IR, R
Eildon (1927, 1955)	Upper Goulburn River	3,390	79	F/C, H/E, IN, IR, R
Thomson (1984)	Thomson River, near Moe	1,175	164	IR, U
Waranga (1910)	Near Rushworth (Swamp)	411	12	IR, U
Mokoan (1971)	Winton Swamp, near Benalla	365	10	IR
Rocklands (1953)	Glenelg River	348	28	R, U
Eppalock (1964)	Campaspe River	312	45	IR, U
Cardinia (1973)	Cardinia Creek, near Melbourne	289	86	U
Upper Yarra (1957)	Yarra River	207	89	U
Blue Rock (1984)	Tanjil River, near Moe	198	75	IN, U
Glenmaggie (1927, 1958)	Macalister River	190	37	IR
Cairn Curran (1958)	Loddon River, near Maryborough	148	44	IR
Yarrawonga (1939)	Murray River	117	22	IR
Toolondo (1952, 1960)	Natural depression, near Horsham	107	-	IR, R
Winneke (1980)	Sugarloaf Creek, near Melbourne	100	89	U
	QUEENSLAND			
Burdekin (1986)	Burdekin River, near Townsville	1,860	55	IR, U
Fairbairn (1972)	Nogoa River, near Emerald	1,440	49	IN, IR, U
Wivenhoe (1985)	Brisbane River, near Ipswich	1,150	59	F/C, H/E, U
Somerset (1959)	Stanley River, near Esk	866	50	U
Fred Haigh (1975)	Kolan River, near Gin Gin	586	52	IR
Ross River (1974)	Near Townsville	417	35	F/C, U
Tinaroo Falls (1958)	Barron River, near Mareeba	407	47	H/E, IR
Awoonga High Dam (1985)	Boyne River, near Gladstone	250	45	IN, U
Glenlyon (1976)	Pike Creek, near Stanthorpe	261	62	IR
Boondooma (1983)	Boyne River, near Proston	212	64	IN, IR
North Pine (1975)	North Pine, near Brisbane	205	44	U
Koombooloomba (1961)	Tully River, near Innisfail	212	52	H/E
Wuruma (1968)	Nogo River, near Eidsvold	194	46	IR
Eungella (1969)	Broken River, near Eungella	131	49	IN, U, IR
Callide Dam (Stage 11) (1986)	Callide Creek, near Bileola	127	35	IR, U, IN
Julius (1977)	Leichhardt River, near Mt Isa	127	35	IN, U
Leslie Dam (Stage II) (1985)	Sandy Creek, near Warwick	108	34	IR, U
Lake Moondarra (1957)	Leichhardt River, near Mt Isa	107	27	IN, U
Beardmore (1972)	Balonne River, near St George	101	17	IR, R, U
	WESTERN AUSTRALIA			
Lake Argyle (Ord) (1971)	Ord River, near Kununurra	5,797	99	F/C, H/E, IR
South Dandalup (1973)	Near Pinjarra	208	43	U
Wellington (1933, 1944, 1960)	Collie River	185	37	IR, R
Serpentine (1961)	Serpentine River	185	55	U
Harding (1985)	Harding River, Pilbara	114	42	IN,U
	TASMANIA			
Lakes Gordon and Pedder (1974)—				
Gordon	South West	11,316	140	H/E
Scotts Peak	South West	2,960	43	H/E
Serpentine	South West		38	H/E
Edgar	South West		17	H/E
Miena (1967)	Great Lake	3,356	28	H/E
Lake St Clair (1938)	Central Plateau	2,000(est.)	3	H/E
Mackintosh (1981)	Mackintosh River, near Queenstown	949	75	H/E
Tullibardine (1981)	Tullibardine River, near Queenstown		25	H/E

MAJOR DAMS AND RESERVOIRS IN AUSTRALIA—*continued*

Name and year of completion	*Location*	*Gross capacity (gigalitres) (a)*	*Height of wall (metres) (b)*	*Purpose*
	TASMANIA—*continued*			
Lake Echo (1956)	Lake Echo	725	19	H/E
Lower Pieman	Pieman River, near Queenstown	641	122	H/E
Arthur's Lake (1965)	Source of Lake River, near Great Lake	511	17	H/E
Lake King William (Clark) (1949, 1966)	Derwent River	541	67	H/E
Devils Gate (1969)	Forth River, near Devonport	180	84	H/E
Rowallan (1967)	Mersey River	131	43	H/E
Bastyan (1983)	Pieman River, near Queenstown	124	75	H/E
Cethana (1971)	Forth River, near Devonport	109	110	H/E
	NORTHERN TERRITORY			
Darwin River (1972)	Darwin River	259	31	U

(*a*) Includes 'dead water', i.e., water below the operational outlet of the reservoir. (*b*) As a general rule, the figures shown for height of wall refer to the vertical distance measured from the lowest point of the general foundation to the crest of the dam, i.e., the level of the roadway or walkway on the dam.

Abbreviations: F/C—Flood control and/or mitigation, H/E—hydro-electricity, IN—Industrial and/or mining, IR—Irrigation R—Rural (stock and domestic), U—Urban supplies.

MAJOR DAMS AND RESERVOIRS UNDER CONSTRUCTION OR PROJECTED

Name	*Location*	*Gross capacity (gigalitre) (a)*	*Height of wall (metres) (b)*	*Purpose*
Crotty Dam	King River, near Queenstown, Tas.	1,091	80	H/E
Proserpine Dam	Proserpine River, near Bowen, Qld	500	45	IR, U
Bjelke Petersen	Barker Creek, near Murgon, Qld	125	33	IR

For footnotes and abbreviations *see* previous table.

Water management

Australia's water resources are managed by a multitude of irrigation authorities, metropolitan water boards, local government councils and private individuals. State authorities dominate the assessment and control of water resources as, under the Commonwealth Constitution, primary responsibility for management of water rests with the individual State governments. The Commonwealth Government is responsible for matters relating to its Territories, and participates indirectly through financial assistance or directly in the co-ordination or operation of interstate projects through bodies such as the River Murray Commission. In other instances where political boundaries intersect some river basins, co-operation between governments has been necessary to develop resources.

Australia's attitudes to water resources management have changed substantially over the last twenty years. Water management is no longer seen just in terms of storing water and regulating streams for consumption, but also in terms of conserving unregulated streams in an unmodified landscape for wild life preservation or recreation purposes or for possible social or economic use by future generations. In addition, agricultural, industrial and urban development has led to greater attention being paid to water quality management.

The development of water resources in the States has an important bearing on the Commonwealth's broad interests in economic management, resource allocation, foreign exchange earnings, distribution of income and related matters. Consequently, the Commonwealth has participated in water resource matters in the States in instances of mutual Commonwealth/States concern or in the national interest.

Commonwealth water policy

In September 1984, the Commonwealth released its new water policy. The objectives are to:

- ensure availability of water, adequate in quantity for all beneficial uses;
- adopt measures which improve the efficiency of water supply and use;
- develop a comprehensive approach to inter-related water and land management issues;
- encourage comprehensive long-term plans for the development and management of water resources;
- implement financial and economic policies which distribute the costs of water supplies equitably and provide incentives for the more economic use of resources at government and individual level.

As part of the new water policy, funds are available to the States and the Northern Territory under a program, the Federal Water Resources Assistance Program (FWRAP), which commenced in 1984–85. Funds are available for purposes which include:

- water resource development or management activities/projects for agriculture, urban or industrial purposes;
- floodplain management;
- collaborative information programs;
- salinity reduction and land drainage;
- State-wide and broad regional water plans;
- public education.

The Country Towns Water Supply Improvement Program, which commenced under the Community Employment Program, has been continued as a sub-program of FWRAP.

Research and continuing assessment of water resources

Australian Water Resources Council—AWRC

The AWRC was established in 1963 by joint action of the Commonwealth and State Governments. The Council consists of the Commonwealth, Northern Territory and State Ministers who have primary responsibility for water resources; it is chaired by the Commonwealth Minister for Primary Industries and Energy.

The Council provides a forum for the water industry. With the shift in emphasis that has occurred in the water industry in recent years from water resource development to resource management and the growing importance of urban water issues generally, the AWRC is extending its scope to focus on industry-wide issues such as pricing and financial policies, resource management, technology and organisational management and strategy. The Council's terms of reference also include the promotion of programs to assess Australia's water resources, the encouragement of education and training in hydrology, the co-ordination and dissemination of information, the promotion of water research, and development of liaison with overseas and international organisations in the field of water resources.

The Council is supported by a Standing Committee, comprising permanent heads of relevant State authorities and the Commonwealth Department of Primary Industries and Energy. CSIRO and the Bureau of Meteorology are also represented and Ministers can nominate additional representatives in accordance with the requirements of the agenda for each meeting.

Following a review held in late 1984, the Standing Committee is now serviced by four advisory committees which consider issues in water industry planning, surface water and catchments, groundwater and water technology. The Council can also establish ad hoc task groups, for advice on particular topics, and is currently being assisted by an Expert Panel on Education and Training, and a National Co-ordinating Committee on Aquatic Weeds.

Water resources assessment

In 1964, in response to a perceived lack of water resources data throughout much of Australia, the Commonwealth Government instituted, through the AWRC, the National Water Resources Assessment Program. The original aim was to expand the stream gauging network in Australia and increase the level of information on groundwater. In 1974, the collection of water quality data was added to the program. The program has been successful in filling many of the data gaps which existed prior to 1964, in providing data and information for water resources planning, construction projects and in the development of the understanding of the nature and function of Australia's water resources. Commonwealth involvement in this program has now ceased. However data collection programs, involving co-operation between Commonwealth and State authorities are continuing in the Murray Basin.

Water resources research

The Department of Primary Industries and Energy is responsible for Commonwealth interests in water resource matters, including research policy and co-ordination.

A water research program was funded and administered on behalf of the Australian Water Resources Council from 1968 until 1984. In June 1985, the Australian Water Research Advisory Council (AWRAC) was established to advise on national water research needs and on a Commonwealth funded program of water research. Funds totalling $3.4 million were allocated in 1986-87 to research programs recommended by AWRAC. Projects included work on salinity, groundwater, stream ecology, water management, water treatment and quality, hydrology and soil/plant water relations; fellowships; and activities to effectively disseminate the results of research. The Murray-Darling Freshwater Research Centre at Albury and the Urban Water Research Association also received financial support.

Water research is undertaken at the Commonwealth level by CSIRO; the Bureau of Meteorology; the Australian Nuclear, Science and Technology Organisation (ANSTO)the Bureau of Mineral Resources, Geology and Geophysics (BMR); and the Alligator Rivers Regional.Research Institute (ARRRI). The water research programs of these major national agencies are co-ordinated through a Water Research Liaison Committee which advises the Ministers of Primary Industries and Energy and of Science and Technology on water research in Commonwealth Government agencies.

At the State level, water agencies have extensive laboratory facilities for water quality testing. However, most water related research is undertaken in research centres associated with agriculture, fisheries, forestry and environmental authorities. At the regional level, some of the larger authorities providing water supply and sewerage services undertake applied research on a very limited scale.

A significant proportion of Australian water research is undertaken by researchers in tertiary education institutions with the aid of either internal funding or grants from outside bodies, such as AWRAC or the Australian Research Grants Committee. Water research is carried out within a range of disciplines, including the biological and social sciences and engineering.

International aspects

International water organisations

Australia liaises with international bodies and United Nations agencies concerned with water resources and participates in their activities in various ways.

Economic and Social Commission for Asia and the Pacific—ESCAP

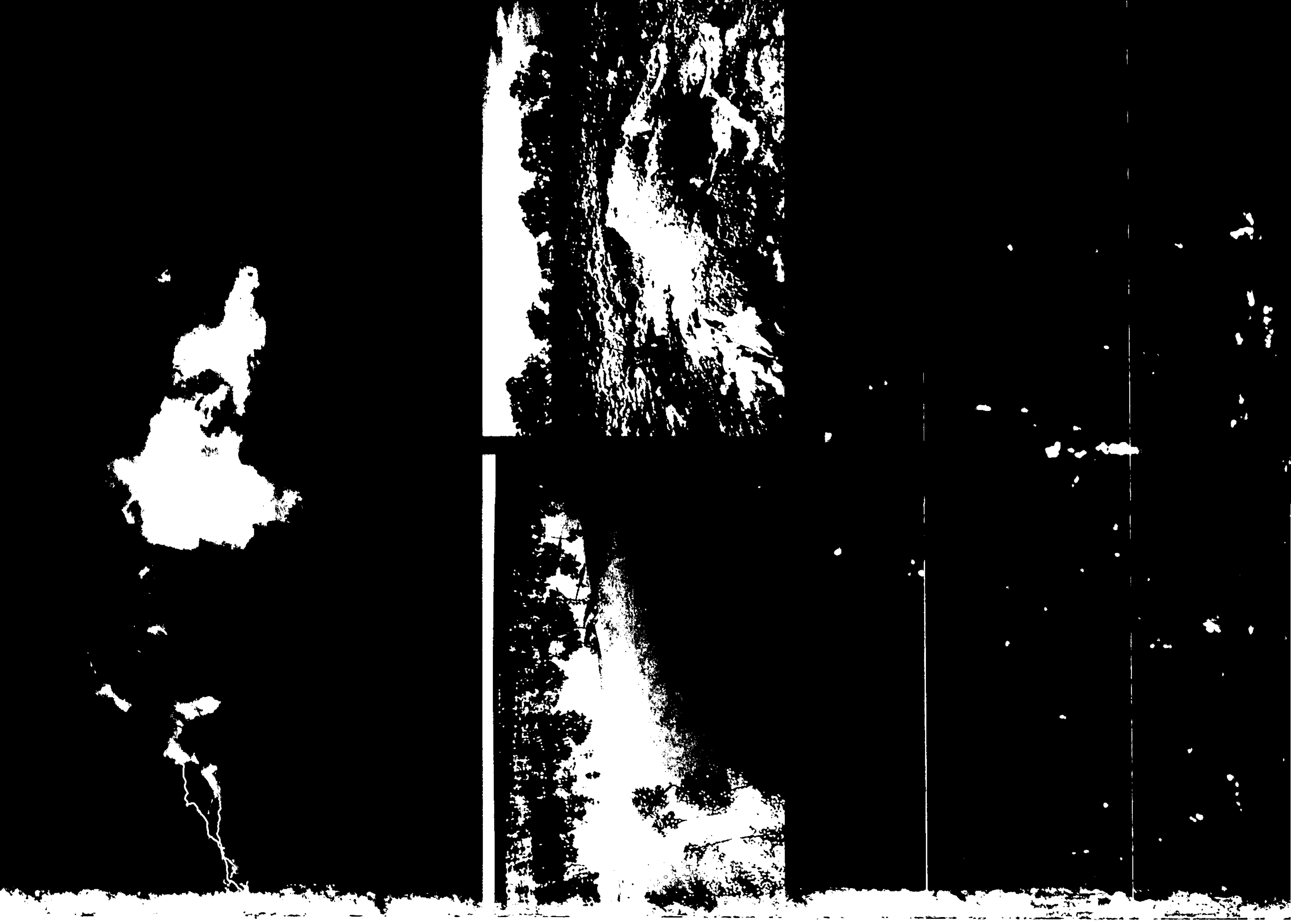
This United Nations Commission, through its Committee on Natural Resources, reports on water policy issues in addition to other activities. By participating in this forum and in seminars arranged on selected topics, Australia contributes to, and benefits from, identification of and discussions on the main problems of water resources management in a densely populated, developing region. Australia is also an active participant in ESCAP's water information exchange system and a contributor to ESCAP's Water Resources Journal and its newsletter, *Confluence*.

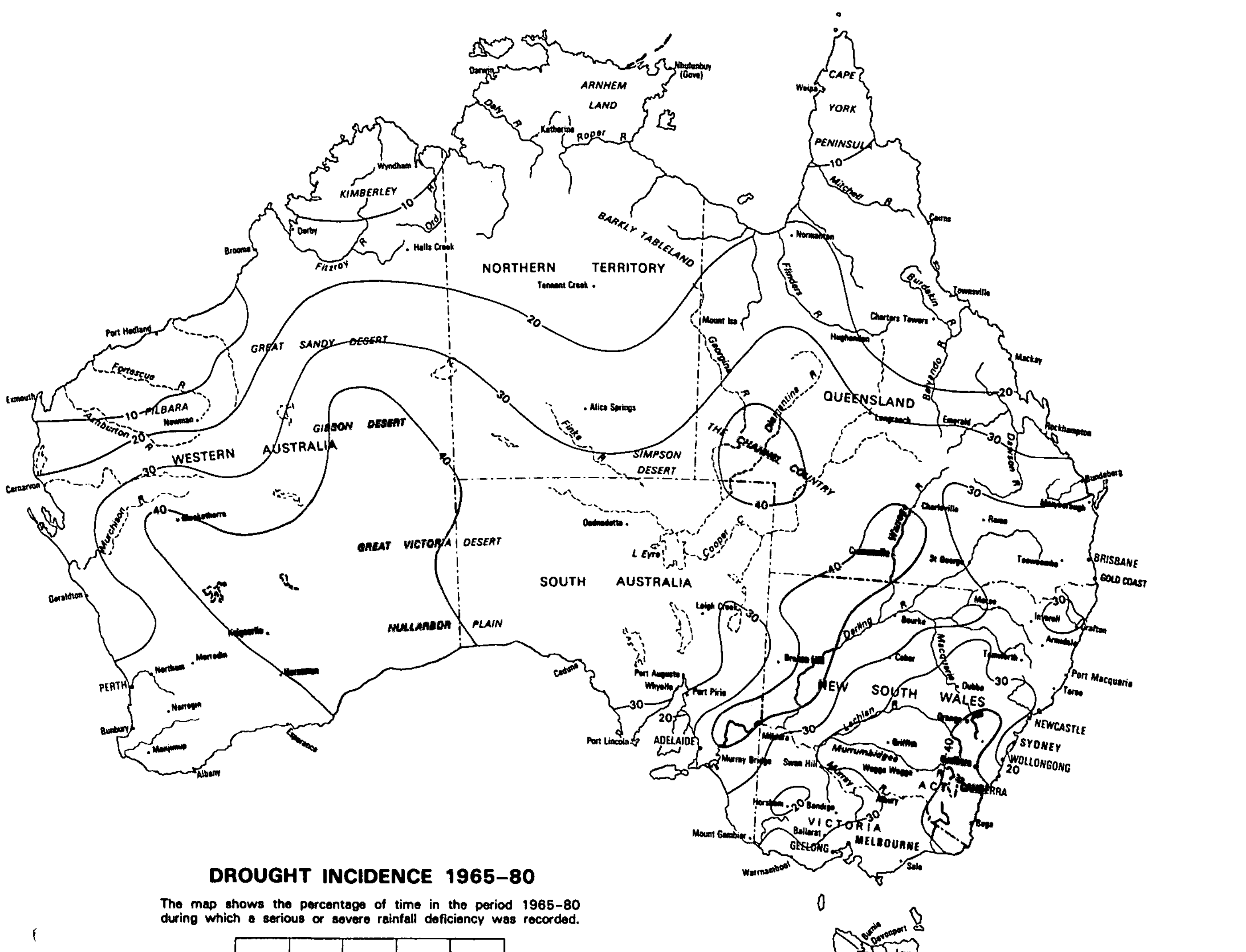
Organisation for Economic Co-operation and Development—OECD

Australia's membership of the OECD since 1970 has involved participation in the work of the Environment Committee, particularly the Natural Resource Management Group, the Water Management Group and its Group of Economic Experts, which investigates problems which are the subject of international concern and the development of strategies to resolve them.

United Nations Educational, Scientific and Cultural Organization—UNESCO

Australia has contributed to the international program designed to advance the science and practice of hydrology and the International Hydrology Program (IHP), through an Australian UNESCO Committee for the IHP. Australia is a member of the Inter-governmental Council for IHP.





DROUGHT INCIDENCE 1965–80

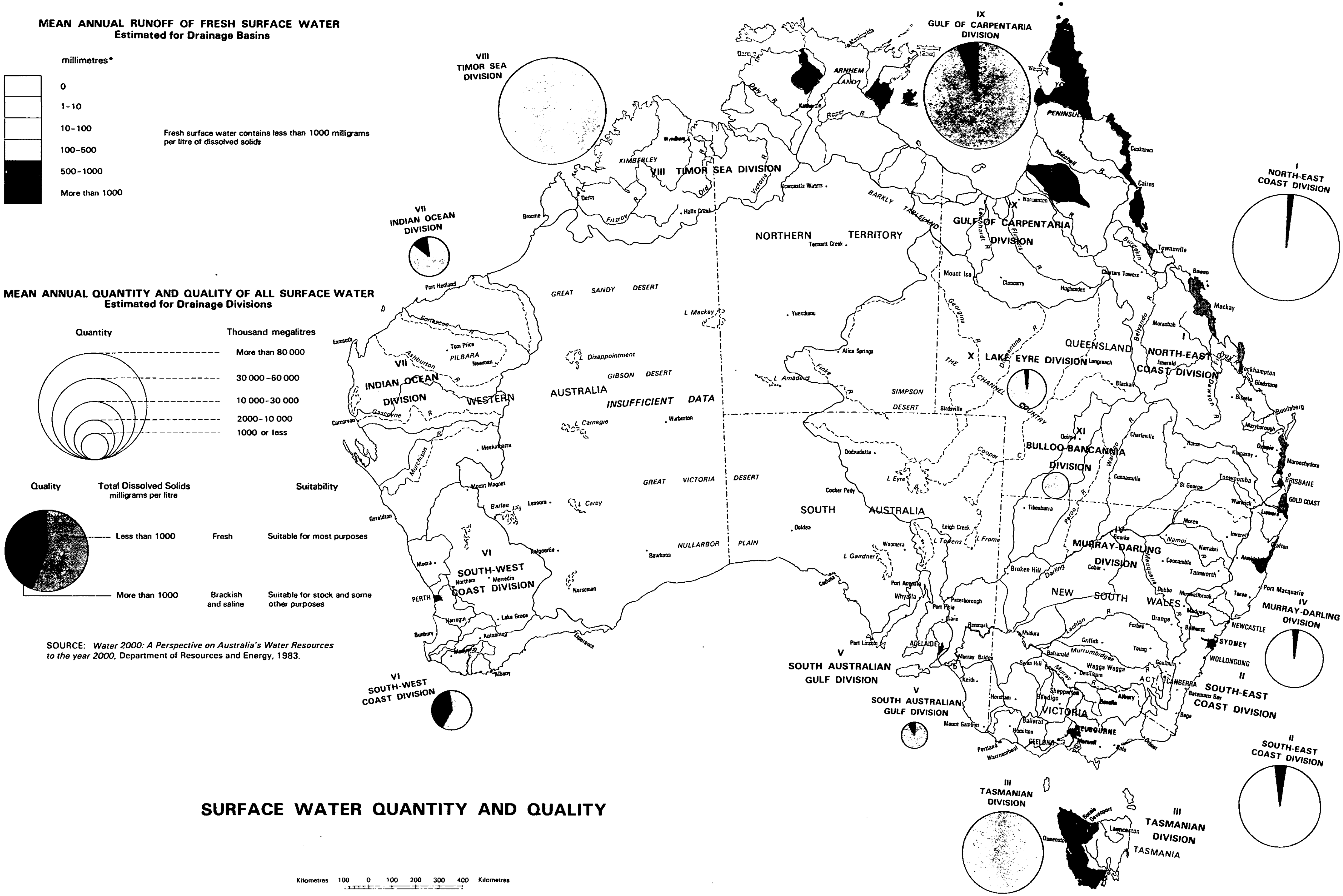
The map shows the percentage of time in the period 1965–80 during which a serious or severe rainfall deficiency was recorded.

10	20	30	40

per cent

SOURCE : Bureau of Meteorology, Drought Statements and Reviews 1-122.

NATMAP
NMP 86/008.11



SURFACE WATER QUANTITY AND QUALITY

NMP 86/008.11

World Meteorological Organization—WMO

Through its Commission for Hydrology, WMO is the specialised UN agency dealing with operational hydrology—the measurement of basic hydrological elements, water resources assessment and hydrological forecasting. WMO has an Operational Hydrology Program (OHP) which is co-ordinated with and complemented by UNESCO's IHP. Within the OHP is the Hydrological Operational Multipurpose Subprogram (HOMS) involving the organised transfer of hydrological technology among members. Australia is a contributor to HOMS and has established a HOMS National Reference Centre within the Secretariat of AWRC. In Australia, hydrological and meteorological activities relative to water resources are co-ordinated by the Secretary of the AWRC as hydrological advisor to the Permanent Representative of WMO in Australia, the Director of Meteorology.

United Nations Environment Program—UNEP

Australia participates in a world registry of major rivers covering discharge and pollutants and of clean rivers so defined and in the development of methodology for analysis and planning of water resources management.

World Health Organisation—WHO

Australia is participating in the water quality monitoring component of the WHO Global Environmental Monitoring System (GEMS) which provides a consistent global overview of changes in water quality.

National and interstate agreements

In the section on water management above, reference was made to the responsibilities of government on the national, State and local authority levels. In this section, some additional details are provided on their roles in the management of water resources.

The flows of many of the tributaries to the River Murray which make up the Murray-Darling Basin have been regulated for irrigation and water supply purposes. Approximately 27 GL of storage has been constructed in the Murray-Darling basin. Of this, about 12 GL of storage has been constructed along the River Murray, including the barrages, locks and weirs. With an average annual diversion from the Murray of approximately 4 GL, the degree of resource utilisation is only approximately 40 per cent.

River Murray Waters Agreement

The *River Murray Waters Act 1915* ratified an Agreement between the Commonwealth and the States of New South Wales, Victoria and South Australia. *Year Books* prior to No. 39 contain a number of summaries of the historical events leading to the Agreement of 1914 which provided for a minimum quantity of water to pass to South Australia. Further details on the River Murray Waters Agreement and subsequent amendments may be found in *Year Book* No. 61, pages 870–2.

The River Murray Commission, established in 1917 to give effect to the Agreement, is responsible for the management of the flow of water in the River Murray, the construction, maintenance and operation of storages and other regulatory works to make water available for irrigation, navigation, stock and urban purposes; and for the allocation of water between the States of New South Wales, Victoria and South Australia. It also has responsibility for management of the catchment above Hume Dam and for the management of the flow of water in the Darling River below Menindee Lakes.

Dartmouth and Hume Reservoirs, together with Lake Victoria and the Menindee Lakes storages, are the key storages operated by the River Murray Commission to regulate the River Murray system. A series of weirs along the river provide for irrigation diversions and pumping facilities by the three States. The major diversion weir is at Yarrawonga. All of the weirs except Yarrawonga have locks to enable navigation of the river to be maintained.

A new River Murray Waters Agreement, which was approved by legislation and proclaimed by the four Governments on 1 February 1984, broadened the role of the River Murray Commission to allow for more direct and independent action in the management of the Murray. The 1984 Agreement enables the Commission to consider water quality, recreation, flood mitigation and environmental issues in relation to the management of the river system, in addition to its traditional role.

In relation to water quality, the Commission is authorised to:

- initiate proposals for the protection or improvement of River Murray water quality;
- co-ordinate or carry out investigations and studies into the feasibility of works or measures for the improved conservation and regulation of the waters of the River Murray, to protect or improve its quality;
- measure and monitor water quality of the waters of the Murray and its tributaries;
- formulate water quality objectives and recommend water quality standards for adoption by the contracting governments;
- make recommendations to contracting governments or any authority, agency or tribunal on any matter which may affect the quality or quantity of the River Murray waters.

A particular feature of the 1984 Agreement is that the State contracting governments are required to advise the Commission of any proposal within their States which could significantly affect the quality and quantity of the River Murray waters.

The Agreement enables the Commission to clearly define the principles of water sharing laid down in the original Agreement; to enable a water accounting system to be introduced and to carry out river protection works and remedial works (including salinity mitigation works) where the need arises. The Commission can also recommend future amendments to the Agreement.

As part of the initiative launched in 1985 by the Commonwealth and the States of New South Wales, Victoria and South Australia to achieve improved management of the natural resources of the Murray-Darling Basin consideration is being given to the establishment of a Murray-Darling Basin Commission to replace the River Murray Commission. The new Commission would encompass the regulatory responsibilities currently provided for under the River Murray Waters Agreement as well as responsibilities for land, environmental and water matters not covered in the Agreement.

New South Wales–Queensland Border Rivers Agreement

As a result of an Agreement between the Premiers of Queensland and New South Wales, Acts were passed by the Parliaments of both States in 1946 and 1947 respectively, establishing the Dumaresq-Barwon, Border Rivers Commission. The Commission is responsible for the conservation and equal sharing of the waters of the Dumaresq River upstream of Mingoola, the regulation of the border rivers downstream of Mingoola and the equitable distribution of the waters of the streams which intersect the Queensland-New South Wales border west of Mungindi.

The duties of the Commission include measurement of stream flows; investigation of proposals for better conservation, regulation and distribution of water resources; and construction and maintenance of dams, weirs, regulators or other works for the storage, regulation and distribution of flows.

The Commission has constructed Glenlyon Dam on Pike Creek in Queensland which has a storage capacity of 261 GL, and a number of regulators and other water distributory works on the river systems under its control.

Snowy Mountains Hydro-electric Scheme

The Snowy Mountains Scheme is a dual purpose hydro-electric and irrigation complex located in south-eastern Australia and on its completion was one of the largest engineering works of its type in the world. It impounds the south-flowing waters of the Snowy River and its tributary, the Eucumbene, at high elevations and diverts them inland to the Murray and Murrumbidgee rivers through two tunnel systems driven through the Snowy Mountains. The Scheme also involves the regulation and utilisation of the headwaters of the Murrumbidgee, Tumut, Tooma and Geehi rivers.

The Scheme was designed and constructed by the Snowy Mountains Hydro-electric Authority, a statutory body established by the Commonwealth Government in 1949, and was substantially completed by 1974. Its installed generating capacity is 3,740 MW and its average annual electricity output is over 5,000 GWh. An average of 2,300 GL of water per year has become available for irrigation in the Murray and Murrumbidgee rivers as a result of the Scheme.

Details of the Scheme are given in a special article, included in *Year Book* No. 70, pages 430–6.

The Snowy Mountains Council, constituted of representatives of the Governments of the Commonwealth, New South Wales and Victoria and the Snowy Mountains Hydro-electric Authority, was established on 2 January 1959. Its main functions are to direct and control the operation and maintenance of the permanent works of the Snowy Mountains Scheme, in particular the control of water and the allocation of loads to generating stations.

States and Territories

The foregoing text deals with water conservation and irrigation in Australia generally and with international, national and interstate aspects. The following material 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, the management of irrigation water supplies is an area of major emphasis, with approximately two-thirds of a million hectares under irrigation. 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, principally to stabilise production of such crops as tobacco, sugar, cotton and pastures. 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 water supplies for population centres and mining and pastoral industries.

New South Wales

Administration

The New South Wales Department of Water Resources was set up in 1987, superseding the previous Water Resources Commission. Its main responsibilities are to co-ordinate policies and programs of all State and local government authorities providing water supplies and other water services; to plan for future water needs; and to operate the rural water supply network, control the use of both surface water and groundwater resources through a licensing system, provide floodplain management and flood mitigation services in non-tidal areas, maintain water resources assessment programmes, and maintain stable river channels.

Water use

In New South Wales, about 14 per cent of all consumptive use of water is by Newcastle-Sydney-Wollongong. By far the largest category of total use in the State is irrigation (74 per cent), while farm uses other than irrigation make up a large part of the remaining 12 per cent.

Urban water

Water supply for Sydney-Wollongong is drawn from seven main storage dams and several smaller storages in the catchments of the Hawkesbury, Georges and Shoalhaven Rivers. Newcastle's water is taken from two storage dams and from groundwater in extensive coastal sand beds. Country towns are serviced variously by dams built specifically for their purposes, by run-of-river pumping, by pumping from rivers in which flows are regulated by irrigation dams, and by groundwater extractions.

Irrigation

The bulk of irrigation development is from rivers of the Murray–Darling Basin, on the inland side of the Great Dividing Range, where both landforms and climate are conducive to large-scale irrigation. Regulated water supplies are provided from twenty-four main storages, including four shared with Victoria and South Australia, and one shared with Queensland.

There are two principal irrigation arrangements. One is licensed irrigation, practised State-wide, in which licensees take water from rivers, usually by pumping, with works constructed by themselves at their own cost. Licensed irrigators use on average 1.5 million ML of water annually. The other is irrigation in nine Irrigation Areas and ten Irrigation Districts, all located along the three most southern inland rivers—the Murray, Murrumbidgee and Lachlan.

The Irrigation Areas and Districts contain over 6,000 individual farms and holdings covering nearly 1.4 million hectares. About half a million hectares is usually irrigated, using 2.8 TL of water. An increasingly used source of water for irrigation is the groundwater in alluvial deposits, mostly in the inland. Extractions from licensed high-yielding bores now approach 300 GL a year.

The annual gross value of production from irrigation is of the order of $750 million—about 20 per cent of the State's total agricultural production—although little more than 1 per cent of all agricultural land is irrigated.

Future program

With large dams on all main inland rivers, there is little prospect of further major irrigation storage construction in the foreseeable future after completion of Split Rock Dam. Attention is to be focussed on improved management and efficiency in water supply and water use, checking and correcting developing problem areas through both management and physical works, and taking stock of the water needs of the natural environment.

Possibilities for greater water efficiency include additional small re-regulating storages along controlled rivers, improved delivery systems, loss reduction and reduction of waste in end-use both in urban areas and on-farm. Increased flexibility is being provided for irrigators through water entitlement transfers and other management measures to enable economic optimisation of production.

Waterlogging and salinisation of farming lands will continue to be addressed by both physical works and management measures. Aging infrastructure works are also to receive attention with modernisation and replacement, while the program of floodplain management and flood mitigation will be continued. Water management procedures in aquatic environments (with first emphasis on wetlands) could be amended following studies currently under way.

Victoria

Administration

Water resources in Victoria are administered by three major agencies, the Department of Water Resources, the Melbourne Metropolitan Board of Works and the Rural Water Commission. The Department of Water Resources is the central policy and planning agency providing advice to the Minister of Water Resources on matters of State-wide interest. The Melbourne Metropolitan Board of Works is a statutory corporation responsible for providing water, sewerage, main drainage and managing waterways and metropolitan parks for the people of Metropolitan Melbourne. The Rural Water Commission is also a statutory corporation and its primary mission is to manage relevant water and land resources, to provide water, water related services and the necessary infrastructure for irrigation, domestic and stock, commercial, industrial, recreational and environmental uses in non-metropolitan areas of Victoria.

Rural water supply systems

The principal irrigation systems in Victoria are:

- **Goulburn-Campaspe-Loddon.** The main storage is Lake Eildon with a capacity of 3,390 gigalitres. The main products in these systems are dairy products, 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.** The Murray Valley Irrigation Area and the Torrumbarry Irrigation System are irrigated by water diverted at the Yarrawonga and Torrumbarry Weirs respectively. These areas are devoted mainly to dairying, fat lambs and canning fruit (Murray Valley) and dairying, fat lambs, vineyards, orchards and market gardens

(Swan Hill). Downstream from Swan Hill, the First Mildura Irrigation Trust and four Commission Districts are supplied by pumping, and produce mainly dried vine fruits, citrus fruits, and table and wine grapes.
- **Southern Systems.** The Maffra-Sale-Central Gippsland district, supplied from the Macalister River and regulated by Lake Glenmaggie, is devoted mainly to dairying.
- **Werribee and Bacchus Marsh.** These districts produce fresh fruit, vegetables and dairy products mainly for the local domestic market. Irrigation is supplied from the Werribee River system which is regulated by three main storages: Pykes Creek, Melton Reservoir and Lake Merrimu.
- **Wimmera-Mallee Domestic and Stock Supply System.** Storages in the Grampian Ranges ensure farm water supplies over the riverless pastoral and cereal lands to the Murray. Without this supply, occupation of the region would be extremely hazardous. There are small areas of irrigation supplied from this system near Horsham and Murtoa.

Future programs

Proposed capital works expenditure by the Rural Water Commission continues to place increasing importance on infrastructure replacement and rehabilitation, urban water services, waterways and floodplain management, environmental protection and water quality improvement.

Major provisions in the program include:
- rehabilitation of headworks—Glenmaggie, Coliban, Melton and Cairn Curran;
- provision of urban water services, excluding water boards and sewerage authorities;
- replacement, rehabilitation and extensions of rural water supplies, including drainage, private diversions and salinity control works;
- management of waterways and related lands, floodplain management and control of flood protection districts.

Queensland

Administration

The control of surface and underground water is exercised by the Commissioner of Water Resources on behalf of the Crown through the licensing of all artesian bores, sub-artesian bores within districts declared for the purpose, and works for the conservation and use of surface water together with the issuing of permits for domestic and stock water use.

In respect of the water resources of the State, the Commissioner is required to prepare a complete description and keep a record of naturally occurring surface and underground water; evaluate the present and future requirements for, and plan the development of, those water resources; take steps to protect the resources from factors likely to be detrimental to their quality or diminish their quantity; investigate and survey any natural water resource; co-ordinate the investigation, evaluation and development of plans for the control of flood-waters and mitigation of flood damage; and construct and manage works for the conservation, replenishment, utilisation and distribution of water.

The Commissioner is principally responsible for water conservation and supply for rural purposes including irrigation, domestic and stock supplies but where possible dual or multi-purpose use is made of works for irrigation, rural, urban and industrial purposes including power generation and mining.

Summary of schemes

Approximately half of the area irrigated in Queensland now uses water from storages constructed by the Queensland Water Resources Commission. The balance is irrigated from unsupplemented surface or underground supplies spread widely throughout the State. Because of the predominance of irrigation by private diversion from streams, as opposed to channel systems delivering water to farms, most of the storages release water to maintain supplies downstream.

Irrigation areas

Approximately one-third of the area irrigated in Queensland each year is concentrated in eight Irrigation Areas constituted under the Irrigation Act where the supply is generally reticulated by channel systems to the farms.

Irrigation areas	*Location and source of supply*
Dawson Valley	Centred on Theodore. Four weirs on Dawson River.
Burdekin River	South of Townsville. Dams and weirs on the Burdekin River and its tributaries and including the Burdekin Falls Dam.
Mareeba-Dimbulah	Hinterland of Cairns. Tinaroo Falls Dam.
St George	Centred on St George. Beardmore Dam.
Emerald	Centred on Emerald. Fairbairn Dam.
Bundaberg	Centred on Bundaberg. Fred Haigh Dam and barrages on the Kolan and Burnett Rivers together with upstream weirs.
Eton	Hinterland of Mackay. Kinchant Dam supplemented by diversion of water from Pioneer River.
Lower Mary River	Upstream from Maryborough. Borumba Dam and barrages on the Mary River and Tinana Creek.

Irrigation projects

These are schemes established under the *Water Act 1926–1983*, where water is released from storages to maintain supplies for pumping under licence to land adjacent to the streams. Details of the projects are set out in the accompanying table.

IRRIGATION PROJECTS, QUEENSLAND, 1985–86

	Authorised allocations				*Actual use*		
	Irrigation		*Other uses (a)*				
Project	*Licenses*	*Allocation*	*Users*	*Allocation*	*Irrigation*	*Other uses*	*Estimated area irrigated*
	No.	megalitres	No.	megalitres	megalitres	megalitres	hectares
Boyne River	54	11,729	—	—	3,391	—	947
Chinchilla Weir	27	3,132	1	1,169	1,601	659	1,120
Dumaresq River	180	62,579	5	1,550	33,493	1,670	8,063
Fitzroy River Barrage	103	13,492	4	—	2,116	108	n.a.
Logan River	113	10,035	4	2,024	7,832	1,681	3,500
Lower Lockyer	193	11,578	—	—	11,958	—	3,000
Macintyre Brook	148	17,375	1	375	9,460	349	3,255
Mary Valley (b)	288	24,872	3	4,014	10,174	3,698	5,730
Three Moon Creek	142	14,607	8	673	7,735	531	3,500
Upper Burnett	195	19,446	4	1,385	19,250	1,274	2,718
Upper Condamine	71	10,927	67	5,807	11,505	4,951	8,158
Warrill Valley	357	15,448	6	16,856	13,510	5,810	10,600
Total	**1,871**	**215,220**	**103**	**33,853**	**132,025**	**20,731**	**50,591**

(*a*) Comprises industrial, urban, waterharvesting, rural water supply, stockwater and other uses. (*b*) Includes water allocations and use in Lower Mary River Irrigation Area.

Rural water supply schemes

Rural water supply schemes based on surface and underground water are constituted under the Water Act to improve water supplies for irrigation, mining, urban, domestic and stock use. These schemes are managed by Boards representing the ratepayers within the areas.

Underground water supplies

The availability of underground water, particularly the Great Artesian Basin, has played a major part in the development of the pastoral industry in Queensland. Underground water is also used extensively for irrigation on individual farms, particularly along the coastal fringe, and for domestic purposes. Some 45 per cent of the area irrigated in Queensland receives its supplies from underground sources. In accordance with the requirements of the *Water Resources Administration Act 1978–1984* the investigation of the availability of underground water is being pursued by geological mapping, investigation drilling and hydro-geological assessment. The predominant areas where water from this source is used for irrigation are the Burdekin Delta, Condamine Valley, Bundaberg, Lockyer Valley, Callide Valley and Pioneer Valley.

Western Australia

Administration

The Minister for Water Resources administers the State operated irrigation schemes under the *Rights in Water and Irrigation Act, 1914–1978*. The Minister is advised by an Irrigation Commission representing the local irrigationists and government, technical and financial branches. Under the *Country Areas Water Supply Act, 1947–1979*, the Minister also administers the water supplies to most country towns and reticulated farmland, as well as controls minor non-revenue producing supplies to stock routes and a few mines and agricultural areas with their associated communities. A small number of town supplies are administered by local boards under the *Water Boards Act, 1904–1979*, 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, the water being channelled from dams in the adjacent Darling Range. The success of dairying and stock raising and, to a lesser extent, vegetable growing, which have replaced citrus growing, has led to a gradual but substantial extension of irrigation areas in the south-west.

Irrigation areas at Carnarvon and on the Ord and Fitzroy Rivers in the Timor Sea Drainage Division are established in the north of the State.

Since the mid-1930s, a centre of tropical agriculture has been developed at Carnarvon, near the mouth of the Gascoyne River. Initially, the principal source of irrigation water for plantations was private pumping from the sands of the Gascoyne River. Overpumping by the growers however, resulted in salt intrusion into the fresh water aquifer. Government controls were introduced and a major groundwater supply scheme upstream of the irrigation area has since been commissioned. A tropical research station is maintained at Carnarvon by the Department of Agriculture.

The Ord River Irrigation Project in the Kimberley Division provides for the eventual development of an irrigation area of some 70,000 hectares of land, one-third of which is in the Northern Territory.

The Camballin Irrigation District on the Fitzroy River floodplain in the West Kimberleys is dependent on diverted river flows and a small volume of storage behind the diversion structures on the Fitzroy River and Uralla Creek.

Country water supplies controlled by the Water Authority of Western Australia

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 the cereal and sheep districts of the State. Two years after the completion of the 1.7 million hectare scheme in 1961, an extension of 1.5 million hectares was agreed to with Federal-State funding.

Goldfields and Agricultural Water Supply

Water for the Eastern Goldfields is supplied by pipeline from Mundaring Reservoir in the Darling Range.

West Pilbara Water Supply

The West Pilbara Water Supply serves consumers in the towns of Dampier, Karratha, Roebourne, Wickham and Point Samson and industrial complexes at Dampier, Cape Lambert and the Burrup Peninsula. Water was previously supplied exclusively from the Millstream groundwater source but the Harding Dam (opened in 1985) will provide 80 per cent of total supply with Millstream providing drought security.

Geraldton Regional Water Supply

The Geraldton Regional Water Supply is supplied principally from the Allanooka groundwater source and a small amount from Wicherina (groundwater plus catchment).

Great Southern Towns Water Supply

This scheme provides water to towns and localities from Wellington Dam to Narrogin and along the Great Southern Railway from Brookton to Tambellup.

Port Hedland Water Supply

The Port Hedland Water Supply supplies Port Hedland, South Hedland and Wedgefield from the Yule River and De Grey groundwater sources.

The Mandurah Regional Water Supply

This scheme obtains supplies from the South Dandalup Dam and the Ravenswood groundwater source.

Local and other Regional Water Supplies

As well as the major water supply schemes above, water is also supplied by the government from seven other Regional Water Supply Schemes to 21 towns and from 104 local water supply schemes to 271 towns. The water comes from a variety of sources including underground, artificial catchments and stream flows.

Aboriginal Communities Water Supplies

Work has commenced on a program to upgrade the water services of remote Aboriginal communities. The program involves providing a town level of service to 40 communities and a support maintenance service to 29 of the 40 communities. Water for these supplies will come predominantly from underground sources.

Underground water

Considerable use is made of groundwater by individual farmers, pastoralists, market gardeners and others, although the water quality varies from place to place and much of it is too saline for irrigation or even stock purposes. Artesian wells throughout the State and non-artesian wells within 'declared' areas must be licensed under the *Rights in Water and Irrigation Act, 1914–1978*. Industries also use groundwater in substantial quantities, especially in the processing of titanium, iron and alumina, and this demand has intensified the search for groundwater.

South Australia

Administration

All major water resources and most public water supply schemes in South Australia are administered by the Engineering and Water Supply Department under the various statutes mentioned below.

- The *Waterworks Act, 1932–1984*, which empowers the Minister of Water Resources to impound or divert the water from any lake, watercourse or underground source for the purpose of establishing and maintaining public water supply schemes to serve proclaimed water districts throughout the State.
- The *Water Conservation Act, 1935–1975*, provides for the control of small reservoirs, bores, tanks, etc. established in remote areas as emergency water supplies or to assist local development.
- The *River Murray Waters Act, 1983*, which ratifies the River Murray Waters Agreement, and under which the Engineering and Water Supply Department operates and maintains Lake Victoria storage, nine weirs and locks downstream of Wentworth, New South Wales, and barrages at the river mouth.
- The *Water Resources Act, 1976–1983*, provides for the management of all aspects of water—surface and underground, quality and quantity. The Act provides for the control of diversions of surface waters from Proclaimed Watercourses and for the withdrawal of underground waters from Proclaimed Regions. It establishes a South Australian Water Resources Council and Regional Advisory Committees as vehicles for public participation in the water resources management process, and a Water Resources Appeal Tribunal to give individuals the opportunity to appeal against decisions of the Minister pursuant to the Act.

Summary of schemes

South Australian irrigation commenced with an agreement involving the Chaffey brothers in 1887 whereby an area was made available for the establishment of certain irrigation works at Renmark. From this start, government, co-operative and private irrigation areas totalling more than 42,000 hectares have been developed in the South Australian section of the Murray Valley. The authority controlling River Murray irrigation is the Engineering and Water Supply Department.

Except for quantities held in various lock pools and natural lakes, no water from the Murray is stored within South Australia for irrigation purposes. In addition to irrigation from the River Murray there are considerable areas irrigated from underground sources.

Adelaide Metropolitan Water Supply

In 1986–87, River Murray pipelines supplied 20 per cent of the total intake to the Metropolitan Adelaide Water Supply System, compared to 53 per cent for the previous year. The principal sources of supply for the nine storages in the Mount Lofty Ranges are the Rivers Onkaparinga, Torrens, South Para, Myponga and Little Para.

Country reticulation supplies

A number of reservoirs in the Barossa Ranges and other local sources are augmented by the Morgan-Whyalla, Swan Reach-Stockwell and Tailem Bend-Keith pipelines which provide River Murray water to extensive country areas. Surface and underground resources have been developed to supply most country centres not covered by the larger schemes.

Murray River irrigation areas

Where irrigation water in excess of plant requirements has been applied, perched water tables develop. Rising to the level of tree roots, these cause the death of orchards from salination and water-logging. Most orchards and vineyards are now drained by plastic and tile drainage systems, thus restoring their health and productivity. Disposal of drainage water is achieved by pumping to basins on river flats where it is evaporated, or by discharge into the river when it is in flood—apart from those areas connected to the Noora Drainage Disposal Scheme, completed in 1984. In the same year, another salinity project, the Rufus River Groundwater Interception Scheme, was commissioned. This scheme involves the intercepting of saline seepage to Rufus River (which flows from Lake Victoria to the Murray) and pumping it to an evaporation basin east of Lake Victoria and outside the river valley.

Tasmania

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. The only large-scale conservation by reservoirs is for hydro-electric power generation, but there are some moderately-sized dams built for mining and industrial interests, for irrigation and by municipal authorities for town water supplies.

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. 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.

Underground water suitable for stock, minor irrigation works and domestic use is exploited in the consolidated rocks of southern, midlands and north-western Tasmania. In some coastal areas, notably King and Flinders Islands, water is obtained from aeolian sands.

The Mines Department is charged with the investigation of underground water resources. There is a great reserve of untapped permanent streams in the western half of the State, which is largely unsettled. The State's rivers discharge in the west, but diversion to the eastern half of the watersheds is not regarded as practicable.

Administration

In Tasmania, water supply was once exclusively the responsibility of local government authorities, but three statutory authorities, the Hobart Regional Water Board, the Rivers and Water Supply Commission and the North West Regional Water Authority, now operate bulk supply schemes. While the Board is responsible for bulk supplies in the Hobart area, the Commission exercises a general control over the use of the State's water resources and the Authority controls water supply to a number of northern municipalities.

Rivers and Water Supply Commission

The Commission is empowered by the *Water Act 1957* 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 for irrigation. The Commission is concerned with drainage trusts' operations, river improvements, irrigation, stream gauging, its own regional water schemes, and with assessing proposals for water supply, sewerage and drainage of towns. It operates in a similar manner to the Hobart Regional Water Board in controlling the water schemes serving the East Tamar region (North Esk Regional Water Supply), the West Tamar area (West Tamar Water Supply) and the Prosser River Scheme near Orford. The North Esk Regional Water Supply Scheme supplies industrial users at Bell Bay and municipalities on the eastern bank of the River Tamar. The West Tamar Water Supply serves the Beaconsfield municipality. The local government authorities retain primary responsibility for reticulation and sale to consumers, except to certain industrial users.

In municipalities not serviced by the Hobart Regional Water Board, the Rivers and Water Supply Commission or the North West Regional Water Authority, the supply of water is a function of the local municipal council.

Irrigation

The Rivers and Water Supply Commission is in charge of three major irrigation schemes, these being the Cressy-Longford Irrigation Scheme (opened in 1974), the South East Irrigation Scheme, Stage I, (opened in 1986), both of which supply water via open channel, and the Winnaleah Irrigation Scheme which supplies water via pipelines.

Of the three schemes, Cressy-Longford is the largest (serving 88 properties) with 10,000 hectares being fit for irrigation. The Coal River Scheme is capable of serving 107 properties, of which 3,800 hectares are fit for irrigation. The Winnaleah Scheme serves 1,500 hectares on 72 properties.

The majority of land irrigated in the State in 1986–87 was watered by private schemes, either by pumping directly from unregulated streams or from on-farm storages. Pasture still predominates as the major crop irrigated, but other vegetables now constitute 33 per cent of the total area irrigated.

Northern Territory

Administration

Under the Northern Territory *Control of Waters Act 1981*, control of natural waters is vested in the Crown. The diversion of water is prohibited except under prescribed conditions. The Act requires that drilling for ground water be carried out only by drillers who are registered under the Act and who are required to provide the government with information on bores drilled. In particular areas, described as Water Control Districts, where stricter control is necessary, the construction or use of a well or water bore without a permit can be prohibited.

Under the *Water Supplies Development Act 1960*, any landholder engaged in pastoral or agricultural production may seek information or advice from the Commissioner of Water Development who is appointed under the Act.

The Water Resources Directorate of the Power and Water Authority is responsible for the assessment, planning and management of surface and groundwater resources throughout the Northern Territory. It carries out systematic stream gauging, the collection of data relating to the quantity and quality of surface and groundwater, flood prevention and control, and waste disposal and baseline inventory. It is involved in water pollution studies and control, and carries out environmental assessments of water and related developments. It also provides an advisory service under the *Water Supplies Development Act 1960* and administers permits and licences under the *Control of Waters Act 1981*.

These arrangements have applied since 1 July 1987. It is proposed that Northern Territory water legislation be amalgamated into a new Act to be called the 'Water Act'.

Surface water

Hydrological investigations and data collection are undertaken across the Northern Territory and the data are published by the Water Resources Group. The program includes base stream gauging stations and pluviographs (automatic rainfall recorders).

Groundwater

For information on Northern Territory groundwater (and surface water) resources see the Northern Territory Department of Mines and Energy's publication *Water Northern Territory—Volume 1*, the Department of Resources and Energy's publications *Australia's Groundwater Resources, 1983* and the Australian Water Resources Council's publication *1985 Review of Australia's Water Resources and Water Use.*

Of 19,596 bores and wells registered in the Territory to 30 June 1987, 24 per cent were for pastoral use, 24 per cent were investigation bores, 33 per cent served urban and domestic supplies, 4 per cent were for agriculture, 11 per cent were used for mining and the remaining 4 per cent for various other uses.

Water supplies

The largest water conservation projects in the Territory are the Darwin River Dam (259.0 gigalitres) and the Manton Dam (15.7 gigalitres) which both serve Darwin with a reticulated water supply. Groundwater from McMinns Lagoon area can be used to augment supply.

Most other towns and communities, including Alice Springs, Tennant Creek, Jabiru and Nhulunbuy, are supplied from groundwater.

Irrigation in the Territory is expanding, but is not extensive, being confined to locations near Darwin, Adelaide River, Daly River, Katherine, Ti Tree and Alice Springs for the purpose of growing fruit, vegetables, fodder crops, pastures and some dairying. Most of this irrigation is carried out using bore water.

There is increasing demand for water resources assessment studies and assistance for relatively small irrigation projects.

Australian Capital Territory

Surface water

Surface water storages supplying A.C.T. (population about 250,000) and the city of Queanbeyan (population about 22,500) are located to the south-west and south-east. The storages to the south-west are in the heavily timbered, mountainous Cotter River catchment within the A.C.T., the storages being Corin Dam (75.5 gigalitres), Bendora Dam (10.7 gigalitres) and Cotter Dam (4.7 gigalitres). The storage to the south-east in New South Wales in the Queanbeyan River catchment (over which the Commonwealth has permanent water rights) on the western slopes of the Great Dividing Range is the Googong Dam (125.0 gigalitres).

The existing storages on the Cotter and Queanbeyan Rivers have an ultimate combined capacity to serve 450,000 persons. The remaining water resource within the A.C.T. is the Gudgenby River which is at present not utilised but has the potential to serve approximately 200,000 persons.

A network of stream gauging stations in the A.C.T. monitors surface water resources while a number of gauging stations are provided with telemeters to provide a flood warning system in association with the Bureau of Meteorology.

Groundwater

Groundwater in the A.C.T. and environs occurs mainly in fractures in crystalline rock such as granite and volcanic rocks; in folded and fractured slate; and, rarely, in solution cavities in limestone. Alluvial aquifers of significance are restricted to the Lake George basin and small areas along mature sections of the Molonglo and Murrumbidgee rivers. Groundwater has been used in the past by most primary producers to augment surface storage. Groundwater production bores in the A.C.T. have yields ranging between about 0.4 and 20 KL per hour; 3 KL per hour is about the average yield. However, many farm bores have fallen into disuse as a result of the government's resumption of freehold land within the A.C.T., and because of the rapid expansion of urban growth. The Bureau of Mineral Resources has provided a bore-siting, groundwater-quality and yield-prediction service in and around the A.C.T. since the early 1950s and has maintained a network of observation bores which have been monitored regularly.

The Bureau of Mineral Resources provides technical advice to landholders and drilling contractors on groundwater and, occasionally, on runoff.

DROUGHT IN AUSTRALIA

(This special article has been contributed by the National Climate Centre, Bureau of Meteorology)

The incidence of drought in Australia to 1968 was surveyed in the 1968 *Year Book* No. 54. The purpose of this article is to bring that survey up to date with information to 1986 inclusive. While broadly summarising the material from the earlier article, the most recent widespread and severe drought in Australia, the drought of 1982–83, is given a special mention. Developments in the Australian Drought Watch Service, operated by the Bureau of Meteorology, and in the monitoring of variations in the climate that can lead to drought are also briefly described.

Definition of drought

Drought in general refers to an acute water shortage. However the term is relative because water availability, which depends on supply and demand, is affected by regional differences in both the climate and the activities of the water user. To a large extent, users adapt to a perception of what is the normal supply for an area but there are other differences. A farmer, for example, is concerned with insufficient water during a season for crops, pastures and stock. A civil engineer in the same area may be more concerned with longer term aspects associated with the storage and managing of water in a reservoir.

On the supply side of the drought equation the main determinants are meteorological and hydrological. It is the former that is given emphasis in this article. A comprehensive coverage of Australia's water resources, including the impact of drought, is given in the series of publications, *Water 2000* prepared for the Australian Water Resources Council in 1983. The broader subject of drought in Australia and the mitigation of its adverse effects has been the topic of many papers and symposia, for example, see the report and recommendations of a drought workshop held in Melbourne by the Royal Meteorological Society in 1986.

The amount of water available for the great majority of users depends on the storage, whether it be in the soil, farm dams, artesian basins, reservoirs and so on. In addition, water availability is affected by losses due to run-off, evaporation and wasteful usage. However the primary indicator of water availability in Australia is rainfall and, given its extensive measurement across the country, rainfall is the most suitable starting point to assess the incidence of drought.

One important aspect of rainfall or more specifically the lack of it, is the difference between aridity and drought, distinguished by Coughlan and Lee (1978) thus: *Aridity implies a high probability of rainfall for a given period below a low threshold. Drought implies a low probability of rainfall for a given period below a relatively low threshold.*

Thus establishing drought criteria is less meaningful for arid zones since the prospects of receiving useful rainfall are significantly lower there than in more abundant rainfall zones. During the dry seasons of the seasonal rainfall zones, e.g. northern Australia, the expectation of useful rainfall can also be quite low and one may think in terms of seasonal aridity. Defining drought criteria for areas with highly seasonal rainfall requires separate consideration and the problem of delineating the onset and retreat of drought in such areas can be quite complex.

Pastoral drought and climatic zones

From a practical viewpoint then, drought is intrinsically related to climatic zones and to the resistance of plants to water shortages. Generally, natural pastures and herbage have evolved to become highly resistant to extended periods of low rainfall particularly in the arid zone. On the other hand, cereal crops such as wheat, being more sensitive to water limitations, require specific treatment in the establishment of criteria for drought.

There are many ways of delineating climatic zones. Those shown for Australia in the diagram on page 211 are based principally on seasonal rainfall characteristics, although evaporation has been taken into account to some extent in the derivation of the zonal boundaries (Bureau of Meteorology, 1975).

In the winter and uniform zones of Australia where agricultural and pastoral activities are more intensive, three consecutive months, although an arbitrary figure, has been found to be an appropriate minimum period for a significant deficiency in the rainfall to develop. Rainfall in the summer rainfall zone is generally more variable when compared with the winter and uniform zones. Coughlan and Lee (1978) have used the summer rainfall zone in northern Australia to illustrate how probabilities of water stress in sown crops may be affected by the expected variability within any one season. Native pastures, in contrast, have evidently evolved to respond more effectively to seasonal rainfall as a whole and are less likely to be affected by the distribution of variable quantities throughout the season. Soil type and the degree to which it has been worked are also significant factors in this regard.

Rainfall in arid zones, as well as being low, is usually highly variable in space and time, and natural pastures and herbage are strongly resistant to such stresses. Drought in an arid zone is generally more appropriate to longer periods, e.g. a year or more, rather than to periods as short as three consecutive months.

Rainfall deficiency and the Australian Drought Watch Service

There have been many attempts to arrive at a satisfactory method of objectively defining drought, establishing criteria for its onset, monitoring its course and declaring a drought ended. Perhaps the most successful approach, and one of the simplest in concept, uses the first decile of accumulated rainfall for a given period as an indicator of drought (Gibbs and Maher, 1967; Lee and Gaffney, 1986). The first decile is simply that amount of rainfall which is exceeded on ninety per cent of occasions for the period of the year specified, e.g. winter, spring or indeed any period of consecutive months. The concept of rainfall deficiency employed by the Bureau of Meteorology is based on a comparison of the rainfall total for at least three months in a specific area with the historical long period record for those three or more months. Thus an area is categorised as having a rainfall deficiency when the rainfall for a period of at least three months falls within the lowest ten per cent (below the first decile) of the historically recorded rainfalls for the same period of the year.

The terms serious and severe rainfall deficiency are defined as follows:

- a *serious rainfall deficiency* exists for a specific period of three (or more) months when the rainfall is above the lowest five per cent of recorded rainfalls, but is less than the ten per cent value;
- a *severe rainfall deficiency* exists for a specific period of three (or more) months when the rainfall is among the lowest five per cent of recorded rainfalls.

When serious or severe deficiencies exist in an area they continue as such until:

(a) rainfall for the past month is already sufficient to rank in the 30th percentile or greater of the recorded rainfalls for the three month period starting with that month (a break due to relatively heavy rainfall), or

(b) rainfall for the past three months ranks in the 70th percentile or greater of the recorded rainfalls for the corresponding three month period (a break due to a series of lesser but overall significant falls).

Rainfall deficiency criteria based on decile values provide the basis for alerting to incipient drought and monitoring the course of extant drought. The procedures, which have been in use in Australia since 1965, have also been adopted by the World Meteorological Organization to monitor drought on a worldwide scale (World Meteorological Organization, 1985). The Drought Watch Service, operated by the National Climate Centre in the Bureau of Meteorology, uses rainfall data from around 800 individual stations throughout the country to provide a monthly statement supported by maps and figures on the distribution of existing rainfall deficiencies (Coughlan, 1986).

Major droughts in Australia

Foley (1957), on the basis of rainfall analyses, classified major droughts in Australia from the early period of European settlement to 1955. He referred to these droughts, summarised in Table 1, as major, severe and widespread and his broad descriptive material indicates that each affected several States covering about one quarter of Australia or more, for varying periods of one or more years. Some of these droughts could be described as drought periods consisting of a series of dry spells of various lengths, overlapping in time and space, and totalling up to about a decade, as in the case of the 1895–1903 drought.

Subsequent to Foley's work, major droughts in Australia have been assessed from time to time using rainfall decile analyses. Typically they have been described as areas of at least serious rainfall deficiency (below the first decile), collectively encompassing at least one quarter of Australia for periods in excess of 10 months. The drought period of 1958–68 and the drought of 1982–83 met these criteria.

TABLE 1: MAJOR DROUGHTS IN AUSTRALIA

Drought period (a)	*Description*
1864–66 (and 1868)	The little data available indicate that this drought period was rather severe in Victoria, South Australia, New South Wales, Queensland and Western Australia.
1880–86	Victoria (northern areas and Gippsland); New South Wales (mainly northern wheat belt, northern tablelands and south coast); Queensland (1881–86, in south-east with breaks—otherwise mainly in coastal areas, the central highlands and central interior in 1883–86); and South Australia (1884–86, mainly in agricultural areas).
1888	Victoria (northern areas and Gippsland); Tasmania (1887–89 in the south); New South Wales; Queensland (1888–89); South Australia and Western Australia (central agricultural areas).
1895–1903	Practically the whole of Australia was affected but most persistently the coast of Queensland, inland areas of New South Wales, South Australia, and central Australia. This was probably Australia's worst drought to date in terms of severity and area. 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.
1911–16	Victoria (1913–15 in north and west); Tasmania (1913–15); 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 (1910–14).
1918–20	Queensland, New South Wales, South Australia, Northern Territory (Darwin–Daly Waters area and central Australia), Western Australia (Fortescue area), Victoria, and Tasmania.
1939–45	New South Wales (severe on the coast), South Australia (persistent in pastoral areas), Queensland and Tasmania; also (more particularly in 1940 and 1944–45) in Western Australia, Victoria, and central Australia; Tennant Creek-Alexandria Downs area in 1943–45.
1958–68	This drought was most widespread and probably second to the 1895–1903 drought in severity. For more than a decade from 1957, drought was consistently prominent and frequently made news headlines from 1964 onwards. This was treated as one major drought period, but could be subdivided into two which overlapped, both in time and space. Central Australia and vast areas of adjacent Queensland, South Australia, Western Australia, New South Wales, and northern Australia were affected, with varying intensity, 1957–66; and south-eastern Australia experienced a severe drought, 1964–68.
1982–83	This extensive drought affected nearly all of eastern Australia, and was particularly severe in south-eastern Australia. Lowest ever 11 month rainfall occurred over most of Victoria and much of inland New South Wales and central and southern Queensland; and lowest ever 10 month rainfall occurred in much of South Australia and northern Queensland. Total losses were estimated in excess of $3,000 million.

(*a*) Major droughts to 1939–45 were classified by Foley (1957). Subsequent droughts were classified by the Drought Watch Criteria (1986).

Australia's most severe drought periods since the beginning of European settlement appear to have been those of 1895–1903 and 1958–68. The 1982–83 drought was possibly the most intense with respect to the area affected by severe rainfall deficiencies. These periods were comparable in their overall impact, but differed appreciably in character.

The 1895–1903 drought period was probably Australia's worst to date, in terms of both its severity and area—affecting practically the whole of Australia at various times but more persistently in parts of eastern and central Australia. Stock and crop losses were apparently the highest in Australian history.

The 1958–68 drought period is described in the article contained in the 1968 *Year Book* No. 54. That drought period was widespread and probably second only to the 1895–1903 drought period in severity. The areas affected and their durations of drought were variable and overlapping.

The 1982–83 drought was notably severe also, especially in south-eastern Australia. This drought was monitored closely and is discussed more fully below.

Droughts of a lesser degree of severity categorised by Foley (1957) are given in Table 2. The droughts of 1970–73 and 1976 were analysed by rainfall deficiency methods based on decile analysis and are appropriate for inclusion in this category.

TABLE 2: DROUGHTS IN AUSTRALIA OF LESSER SEVERITY

Drought period (a)	*Description*
1922–23 and 1926–29	Queensland (severe); New South Wales (intermittent); Western Australia (more particularly Fortescue: 1922–29); South Australia (mainly pastoral areas); central Australia (1924–29); Northern Territory (1926–29); Victoria (1925–27; severe in the north 1925–29) and Tasmania (1925–27, not continuous).
1933–38	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 (1935–36 in pastoral areas and 1938 in agricultural areas) and northern Tasmania (1935–37, not continuous).
1946–49	Queensland (central coast and highlands and central interior, elsewhere mainly in 1946); Northern Territory and New South Wales (mainly in 1946–47); Western Australia (more particularly in central agricultural areas, 1947–50), and northern Tasmania (1948–49).
1951–52	Queensland and Northern Territory; and Western Australia, especially pastoral areas (1951–54).
1970–73	Prolonged drought over the north-eastern goldfields of Western Australia and adjacent areas, caused by successive below average rainfall years.
1976	Western New South Wales, most of Victoria and South Australia due to failure of autumn-winter rains; break in September 1976.

(*a*) The droughts to 1951–52 inclusive, were classified by Foley (1957). The subsequent droughts, 1970–73 and 1976, were classified by the Drought Watch Criteria (1986).

Severe droughts in south-eastern Australia

South-eastern Australia is taken to include New South Wales, southern Queensland, Victoria, Tasmania and the settled parts of South Australia; it contains about 75 per cent of the nation's population, and major droughts affecting the region have a markedly adverse impact on the economy. Severe droughts in south-eastern Australia are usually caused by a failure of the winter-spring rains and may extend through summer to the following autumn.

A severe drought is defined here in general terms as a drought in which ten or more rainfall districts are substantially affected by rainfall deficiencies for eight or more months. The onset of drought is taken as the month in which rainfall drops below average, and which marks the start of a period with serious rainfall deficiencies (below the first decile) lasting three months or more. A drought is considered broken when rainfall meets the criteria defined previously.

TABLE 3: SEVERE DROUGHTS IN SOUTH-EASTERN AUSTRALIA

Drought period (a)	*Area affected*	*Average duration and month of break*	*Descriptive remarks*
1888	Southern Queensland, most of New South Wales, Victoria, South Australia and parts of Tasmania	9–10 months to January 1889	In parts of northern New South Wales, not broken until autumn 1889
1902	New South Wales, Victoria, parts of southern Queensland, South Australia and Tasmania	Victoria, South Australia and Tasmania: 9 months to December 1902 New South Wales and southern Queensland: 12 months to 1902	Considerable overlapping of affected areas
1914–15	Victoria, New South Wales west of the tablelands, settled areas of South Australia and most of Tasmania	South Australia: 11–12 months to June 1915 Northern Victoria and New South Wales: 10–12 months to June/July 1915 Southern Victoria: 16 months to May/June 1915	Rainfall during 1913 also below average in parts of south-eastern Australia; and much of Victoria and western New South Wales had some relief in the summer of 1914–15
1940–41	Most of New South Wales, Victoria, South Australia and eastern Tasmania	South Australia: 6 months to January 1941 Tasmania: 8–9 months to January 1941 Victoria: 11 months to January 1941	Variable durations in New South Wales
1944–45	Most of New South Wales, Victoria and South Australia	South Australia and south-western Victoria: 4–6 months to summer 1944–45 Southern Victoria: 12 months to August 1945 Northern Victoria and southern New South Wales: 15–19 months to August 1945 Northern New South Wales: 15–17 months to June 1945	Well below average rainfall in parts of South Australia in April–June 1945; and 1943 was also a dry year in parts of south-eastern Australia
1967–68	Victoria, southern New South Wales, South Australia and Tasmania	South Australia: 12–13 months to March 1968 Tasmania: 15–16 months to May 1968 Victoria and New South Wales: 14–15 months to May 1968	Other extensive parts of Australia affected during 1958–67
1972–73	Most of Victoria, western and central New South Wales, South Australia and north-eastern Tasmania	9–10 months ending February 1973	Drought broke in February 1973; except in north-eastern Tasmania, where it broke in autumn 1973
1982–83	Victoria, most of New South Wales, South Australia, southern Queensland and Tasmania	Generally 11 months ending February 1983 Tasmania: 9 months ending February 1983	Drought broke in autumn 1983

(a) The drought periods prior to 1965 inclusive, occurring prior to the operation of the Drought Watch Criteria, have been re-assessed applying those criteria. The specified severe droughts in south-eastern Australia are actually encompassed within the major droughts in Australia contained in Table 1 (except 1972–73).

These past, severe droughts were investigated (Bureau of Meteorology, 1983) using seasonal rainfalls over south-eastern Australia based on a limited network of rainfall stations and previously published material. Droughts after 1914 were identified using also the district rainfall data. Two earlier droughts affected south-eastern Australia, in 1864–66 and 1880–86, but rainfall data for these are incomplete. The 1918–20 period was also significantly drought affected without quite meeting the criteria.

Of these eight severe droughts in south-eastern Australia, four ended in summer (1888, 1902, 1940–41, 1972–73). Two droughts (1967–68 and 1982–83) broke in autumn. The remaining two (1914–15 and 1944–45) generally persisted until the following winters, although there were useful summer rains over a significant portion of the drought affected areas.

The 1982–83 major drought

The following figure indicates the severity and extent of the 1982–83 major drought in terms of rainfall deficiency over the extensive areas where rainfall for the duration of the drought, approximately ten to eleven months, was the lowest on record. This was due to a widespread failure of the winter and spring rains of 1982. By the end of February 1983, in this vast area of eastern Australia, only small parts of south-east Queensland, adjacent north-east New South Wales and parts of south-west and north-east Tasmania were free from drought.

In the far south-eastern part of the continent the drought was markedly severe. Virtually all of Victoria and southern New South Wales had registered record low rainfall for the eleven months, April 1982–February 1983 inclusive. Much of the settled areas of South Australia had recorded their lowest ever rainfall for the ten months, May 1982–February 1983 inclusive.

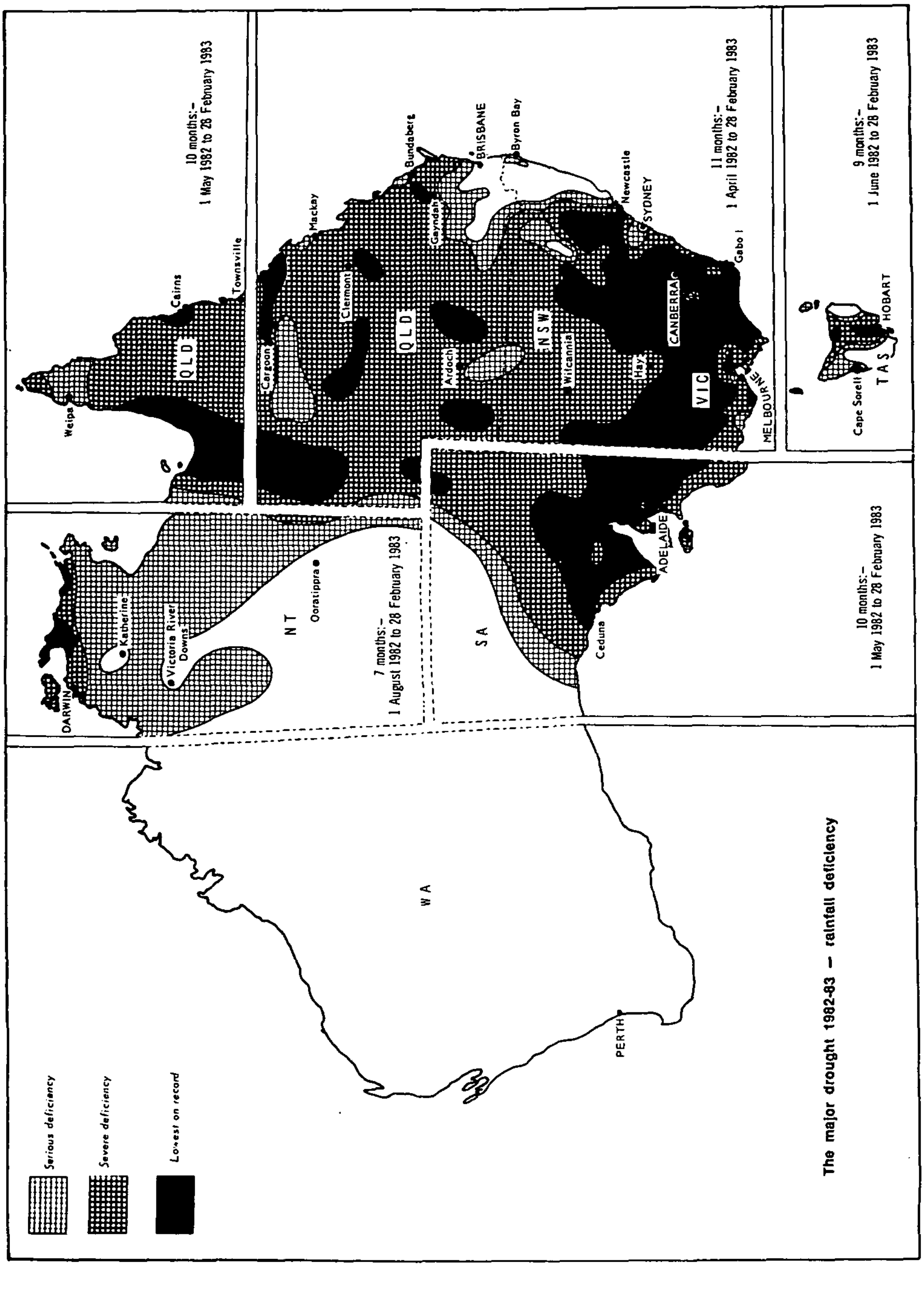
It is generally agreed that the widespread bushfires which culminated in the enormous conflagrations of Ash Wednesday, 16 February 1983, were a direct consequence of the preceding drought conditions. Total losses caused by the drought were estimated by the Australian Government to exceed $3,000 million; and estimates of losses in south-eastern Australia exceeded $1,200 million.

Widespread heavy rains in March 1983 significantly reduced the extent of the drought over eastern Australia. Heavy April rains further decreased the area of the drought, and record May rains left only small scattered remnants at the end of autumn 1983.

Physical causes of drought

The physical causes of drought, as distinct from the socio-economic factors that may induce stress in association with below average rainfall (e.g. *see* Coughlan, 1985), have their origins in the fluctuations of the global climate system. There are many possible reasons why the weather during a particular month or season will differ from one year to the next. The climate system as a whole is an extremely complex mix of different sub-systems all interacting with each other on a wide range of time and space scales, e.g. the atmosphere, oceans, ice masses and the biosphere. The potential for variability from year to year and decade to decade therefore is very high. Given this high level of 'internal' variability, the significance or even the reality of possible external influences from sunspots, phases of the moon and so on, remains highly questionable on time scales shorter than millenia.

The fact that variability in time and space is an inherent character of the climate means that droughts of varying extent and severity must also be an inherent part of this variability. With an increase in understanding of how the various parts of the climate system fit together and interact with each other, is coming a greater understanding at least of what causes the larger scale droughts. Perhaps the most widely known climatic anomaly that has developed every few years is the so-called El-Nino phenomenon. El-Nino, a name given to an anomalous warm ocean current off the equatorial Pacific coast of South America is part of a much wider system affecting the whole of the Pacific Basin and probably the whole globe. The appearance of an El-Nino is very often associated with below average rainfall over much of eastern Australia. El-Nino is linked to a swing in the mean atmospheric pressure difference across the Pacific Ocean called the Southern Oscillation. Many of the widespread and severe droughts affecting eastern Australia identified above were a direct consequence of a marked swing in the Southern Oscillation.



The major drought 1982-83 — rainfall deficiency

Monitoring the weather and climate

With a growing international awareness of the social and economic impacts of climate variability, including drought, the World Meteorological Organization (WMO) in the late 1970s instituted a World Climate Programme (WCP) to complement its long established World Weather Watch Programme. The WCP is the formal framework for international co-operation in climate data exchange, climate monitoring, applications of climate data, climate research and the impacts of climate variability on man and the environment. As a national focus, some countries (e.g. U.S.A. and Canada) have established National Climate Programs.

Australia's Bureau of Meteorology plays a key role in international data exchange and analysis by operating in Melbourne one of the three World Meteorological Centres (WMC), the other two centres being in Washington and Moscow. The Melbourne WMC and a Regional Meteorological Centre in Darwin, also operated by the Bureau, collect and process weather and climate data for the southern hemisphere. These Centres issue daily weather analyses and forecasts for the southern hemisphere, eastern Asia and the western equatorial Pacific.

The National Climate Centre (NCC), in addition to its monitoring of fluctuations in Australia's climate, carries out analyses of monthly and seasonal variations of atmospheric pressure, temperature and wind over the southern hemisphere as a whole. The analyses are contained in the NCC's monthly Climate Monitoring Bulletin accompanied by seasonal indications, outlooks and inferences when feasible. Information is regularly exchanged between similar climate centres operating in other countries.

The Bureau of Meteorology Research Centre has also instituted a program of research into the problems of forecasting climate fluctuations on monthly and seasonal time scales. Any improvements in this regard would have far reaching implications for our ability to cope with drought. Already there are signs of some skill in using the new found knowledge of the Southern Oscillation/El-Nino phenomenon to assess the likelihood of major anomalies in winter/spring rainfall over eastern Australia several months in advance.

Conclusion

Since the 1860s there have been nine major Australian droughts. The major drought periods of 1895–1903 and 1958–68 and the major drought of 1982–83 were the most severe in terms of rainfall deficiency and their effects on primary production. In south-eastern Australia the droughts of 1967–68 and 1982–83 were notably extreme. There have been six other droughts of a lesser degree of intensity, but nevertheless causing appreciable losses in large areas of several States. In south-eastern Australia there have been eight severe droughts, mostly encompassed within the major Australian droughts.

Droughts will continue to be a prominent feature of the Australian scene. Improved meteorological drought watch services and hopefully an improved ability to forecast droughts through local research and participation in the WCP will help to mitigate their adverse impacts. The nature of drought, however, and the way in which the community should deal with it are complex issues incorporating significant variables in fields such as hydrology, agriculture, economics and sociology, as well as in the political realities of the day.

BIBLIOGRAPHY

Special Article

BUREAU OF METEOROLOGY. *Climatic Atlas of Australia.* Map Set 5 'Rainfall', Melbourne, 1975.

—— *Drought Review Australia.* February 1983, Accompanying Notes, Melbourne, 1983.

COUGHLAN, M. J. and LEE, D. M. 'The Assessment of Drought Risk in Northern Australia', *Natural Hazards Management in North Australia.* Printed by A.N.U., Canberra, 1978.

COUGHLAN, M. J. 'Drought in Australia', *Natural Disasters in Australia.* Printed by Australian Academy of Technical Sciences, Parkville, Victoria, 1985.

—— *Monitoring Drought in Australia.* International Symposium and Workshop on Drought, Lincoln, Nebraska, 1986.

FOLEY, J. C. *Drought in Australia*. Bulletin No. 43, Bureau of Meteorology, Melbourne, 1957.

GIBBS, W. J. and MAHER, J. V. *Rainfall Deciles as Drought Indicators*. Bulletin No. 48, Bureau of Meteorology, Melbourne, 1967.

LEE, D. M. and GAFFNEY, D. O. *District Rainfall Deciles—Australia*. Meteorological Summary, Bureau of Meteorology, Melbourne, 1986.

RESOURCES AND ENERGY, DEPARTMENT OF. 'Water Resources Aspects of Drought in Australia', *Water 2000: Consultant's Report No. 13*. AGPS, Canberra, 1983.

ROYAL METEOROLOGICAL SOCIETY, AUSTRALIAN BRANCH. *Report and Recommendations of the Drought Workshop, May 1986*. Melbourne, 1986.

WORLD METEOROLOGICAL ORGANIZATION, WORLD CLIMATE DATA PROGRAMME. *Climate System Monitoring*. Monthly Bulletin, Issue No. 15, Geneva, 1985.

Further References

ABS PUBLICATIONS

Agricultural Land Use and Selected Inputs, 1985–86, Australia (7411.0)

Other Publications

NATIONAL DEVELOPMENT AND ENERGY, DEPARTMENT OF. *Review of Australia's Water Resources*. Australian Water Resources Council, Canberra, 1975.

RESOURCES AND ENERGY, DEPARTMENT OF. *Review of Australia's Water Resources and Water Use*. Water Resources Data set. Australian Water Resources Council, 1985.