## CHAPTER 11

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## IRRIGATION MANAGEMENT

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Most of Australia lies within the arid belt between latitudes of 15ºS and 35ºS where rainfall is meagre and unreliable by world standards. Compared to the world average rainfall of 660 mm per year, the Australian continent receives, on average, only 469 mm rainfall, of which approximately 88% is lost to evapotranspiration, 11% to runoff as river flow and 1% to ground water recharge. A feature of rainfall in Australia is the wide diversity both spatially and between years.

During the past 150 years, periodic droughts have had disastrous economic effects on primary production throughout Australia. From 1864 to 1992 there were thirteen droughts of major proportions as well as numerous localised droughts of lesser national significance. In the 1895-1903 drought, the sheep population was reduced from 106 million to 53 million. It took 30 years for these numbers to build up again, only to be substantially reduced in the devastating drought of the mid-1940s.

The lack of reliable water supplies in many parts of Australia and the consequences of drought on the national economy, and in particular on livestock and crop production, highlighted the need to initiate a water conservation program.

There was considerable public enthusiasm for irrigation development, particularly in the early 1900s. The first irrigation scheme was established in 1859 on a farm fronting the Yarra River near Melbourne. In 1886, the Irrigation Act of Victoria was enacted to rationalise all surface water resources and to enable the formation of irrigation trusts to construct and administer the various works (Anderson, 1974).

Under Section 100 '***Nor Abridge right to use water***' of the Australian Constitution, water resource management is the responsibility of the State and Territorial, viz:

> ***The Commonwealth shall not, by any law or regulation of trade or commerce, abridge the right of a State or of the residents therein to the reasonable use of waters of rivers for conservation or irrigation. -*** The Constitution of the Commonwealth of Australia.
>
> **-** The Parliament of the Commonwealth of Australia (1987)

At the turn of the century, as many as ninety trusts were operating in Victoria. However, by 1905, the administration of water resources in Victoria was assumed by the newly created State Rivers and Water Supply Commission (Anderson, 1974). All trusts were abolished except for the First Mildura Irrigation Trust, which is still in operation. This scheme, as well as a similar pumping scheme at Renmark in South Australia, was established in 1889 by the Chaffey Brothers, who had developed irrigation projects in California. The development at Renmark gave the impetus for further irrigation development along the Murray River, mainly for horticultural crops such as citrus and grapes.

The Victorian and South Australian irrigation activities prompted some action in new South Wales. The first farm irrigation scheme was started in 1890, at Curlwaa, at the junction of the Murray and Darling rivers. Two years later, the Hay Irrigation Trust on the Murrumbidgee River was established.

In 1899, Sir Samuel McCaughey bought North Yanco estate on the banks of the Murrumbidgee River and developed his ideas of irrigation which were to become the start of the Murrumbidgee Irrigation Areas. McCaughey used a system of pumps, a main canal and distribution channels to successfully irrigate forage crops and lucerne.

The Burrinjuck and Murrumbidgee Construction Act was passed in 1906, authorising the construction of Burrinjuck Dam on the Murrumbidgee River near Yass and the design and construction of an irrigation scheme centred on Yanco, NSW. Water from the Murrumbidgee Irrigation Areas was first supplied on 13 July 1912 to Yanco. The Department of Public Works initially administered the scheme, but the NSW Government soon realised that water conservation and irrigation required special attention. Thus, in January 1913, the Water Conservation and Irrigation Commission was established to undertake the administration and control of all water conservation and irrigation schemes in rural areas of New South Wales. This body was superseded in April 1976 when the Water Resources Commission was formed, with additional responsibilities including underground water resources.

Since 1995 the conservation of water and soil in New South Wales has been the responsibility of the Department of Land and Water Conservation (DLWC) which subsequently commenced privatisation of irrigation schemes. The DLWC is responsible for selling water to individual land holders and irrigation companies. The latter are responsible for the delivery of water to individual holdings and ensuring that irrigation activities do not adversely impact on the environment.

Irrigation development occurred much later in Queensland. The first large-scale irrigation project in tropical Australia was the Mareeba-Dimbulah Irrigation Area, which was completed in 1959 (Anderson, 1974). The Burdekin River Scheme was developed in 1986 for the sugar cane and rice growing industries but rice production ceased in that State in 1993. All water resources in Queensland are controlled by the Department of Natural Resources and Mines, including underground waters on which a large proportion of the State's irrigation depends.

In Western Australia the relatively small area of 11,500 hectares in the Kimberley is irrigated each year with water from Lake Argyle on the Ord River. The first crops of cotton grown in the 1970s failed due to pests and this region developed a reputation for being unviable. However, sugar, vegetables, and some fodder crops have since been successfully produced. The capacity of Lake Argyle was increased in the 1990s and the Ord Stage II expansion of 44,000 hectares is due to commence early in the 21st century.

Tasmania, the Australian State which has the best rainfall:evaporation water balance of any Australian region is not exempt from large seasonal and year-to-year variation in climate and it also relies on irrigation to support its crop, horticultural and pasture industries.

The Murray-Darling Basin continues to be the most important area of irrigation. Despite the fact that this region comprises only 14% of the Australian landmass, it contains about 71% of all irrigated land, including the major irrigation areas and districts of southwestern New South Wales and the northern plains of Victoria. The river systems are of vital importance to these irrigation activities, the major contributions coming from the Murray, Murrumbidgee and Goulburn rivers. In order to ensure continuity of water supplies for irrigation, emphasis has been placed on the construction of large storage dams which provide flood control, allow the generation of electricity in some cases and regulate river flows to provide water for irrigation schemes.

More comprehensive accounts of early irrigation developments are given by Smith *et al.* (1983) and Fullerton (2001). The significance of irrigation to agricultural production is indicated by the 25% increase in the area under irrigation between 1984 and 1998 (NLWRA 2000). The extent of irrigation in Australia is shown in Figure 11.1.

## AVAILABILITY OF WATER FOR IRRIGATION

Analysis of the climatic features of the Australian environment (Chapter 2) shows that plant productivity is limited by a water insufficiency over the majority of the continent. Ensuring a reliable supply of water throughout the year could raise this productivity. A survey of the water resources in Australia is therefore warranted, taking into account not only the amount of water but also its dependability and quality.

### Topographical Features

The lack of high mountain ranges over most of the continent is a major factor affecting rainfall and drainage patterns. Only 2% of Australia lies above 1000 m. The most notable range is the Great Dividing Range in the east, Mt Kosciuszko being the highest point at 2228 m. However, these mountains are close to the eastern seaboard, give rise to relatively short coastal river systems which drain to the sea and account for most of the annual discharge. A significant exception is the Murray-Darling system.

The remaining 70% of the continent is interior lowlands with drainage patterns characteristic of semi-arid and arid conditions (Figure 11.1). These include disconnected ephemeral river systems and terminal salt lakes. There are 246 river basins and 69 ground water provinces across Australia.

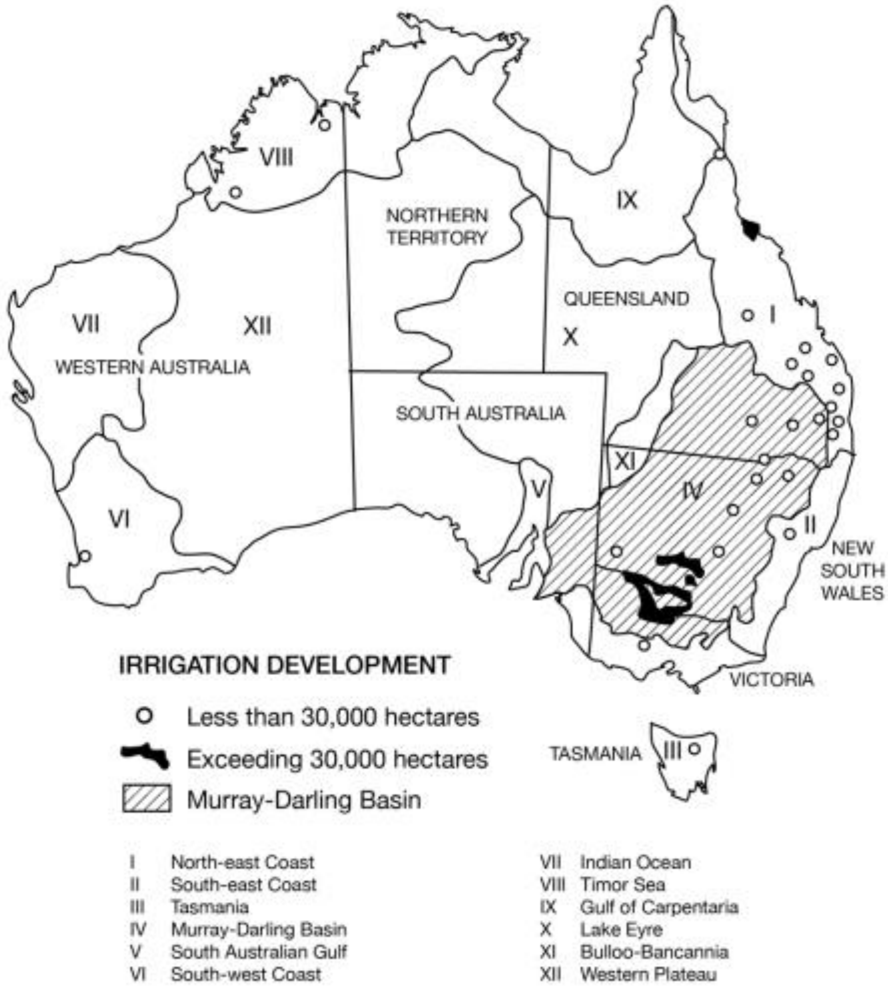


Figure 11.1 The distribution of the principal irrigation lands in Australia in association with the drainage system of the continent (adapted from Meyer, 1992)

**Runoff**

The total surface runoff of about 440 million megalitres in rivers varies widely between regions. There is negligible runoff in the South Australian Gulf, Lake Eyre or Western Plateau regions (V, X and XII in Figure 11.1), while 78% of the total runoff is contributed by the north-east coast, Tasmania, Timor Sea and Gulf of Carpentaria regions which are only 22% of the land area (regions I, III, VIII and IX in Figure 11.1; Smith, 1998). The runoff from only one region, Tasmania, exceeds the world average and there are no significant irrigation schemes utilising the waters which flow to the seas in the north and north-west

***Seasonality***

The pronounced seasonality of rainfall over the continent creates a similar pattern with respect to runoff. In northern Australia the flow is concentrated in the summer months, whilst in the south the discharge is concentrated, though to a lesser extent, in the winter months.

This pronounced fluctuation results in large rivers in the north, for example, having flow rates of 30 ML/second or more, in high flood. The same rivers may cease to flow altogether in the winter day season.

Because of this seasonality, any regional development must necessarily provide for surface water storage to take account of the variability of flow of surface waters. The costs of this storage are high because, in addition to storage for irrigation and other purposes, there is a need to provide adequate spillway capacity to ensure safety in flood times. These costs are accentuated by the very high evaporation losses from surface water storages.

Table 11.1 Water use (as a percentage of total water use) and population, by drainage division (Smith, 2000)

| | | Irrigation | | | | Urban and Industrial | | |
|---|---|---|---|---|---|---|---|---|
| Drainage Division | Total Use ($10^3$ ML) | Pasture (%) | Crop (%) | Horticulture (%) | Rural (%) | Domestic (%) | Industrial/ Commercial (%) | Population (millions) |
| North-east Coast | 1660 | 4.3 | 48.4 | 5.6 | 9.0 | 21.3 | 11.4 | 2.2 |
| South-east Coast | 2530 | 28.1 | 5.4 | 7.0 | 5.7 | 29.5 | 24.3 | 8.2 |
| Tasmania | 174 | 26.4 | 26.9 | 2.3 | 6.5 | 18.9 | 19.0 | 0.4 |
| Murray-Darling | 8660 | 47.6 | 28.2 | 12.7 | 7.9 | 2.6 | 1.2 | 1.8 |
| South Aust. Gulf | 312 | 9.0 | 0.8 | 14.4 | 12.1 | 45.2 | 18.5 | 1.2 |
| South-west Coast | 678 | 24.8 | 3.5 | 11.0 | 4.4 | 31.1 | 25.2 | 1.2 |
| Indian Ocean | 64 | 0.2 | 2.6 | 10.7 | 12.2 | 38.0 | 36.3 | 0.1 |
| Timor Sea | 128 | 15.3 | 35.6 | 4.0 | 12.7 | 18.0 | 14.4 | 0.1 |
| Gulf of Carpentaria | 244 | 6.8 | 18.4 | 5.2 | 46.3 | 6.0 | 17.3 | <0.1 |
| Lake Eyre | 135 | 0.1 | 2.5 | 0.0 | 83.7 | 6.0 | 6.3 | <0.1 |
| Bulloo-Bancannia | 18 | 0.0 | 0.0 | 0.0 | 97.3 | 1.2 | 1.5 | <0.1 |
| Western Plateau | 41 | 0.0 | 0.2 | 1.0 | 47.2 | 21.7 | 29.9 | <0.1 |
| TOTAL | 14600 | 35.4 | 24.3 | 10.3 | 9.1 | 12.2 | 8.7 | 15.4 |

**Surface Waters**

Not all of the water in streams and groundwater deposits is available for irrigation purposes. The DPIE (1987) introduced the term *divertible resource* - defined as 'the average annual volume of water which, using current technology, could be removed from developed or potential surface or groundwater sources on a sustained basis, without causing adverse effects or long-term depletion of storages.' There is a growing appreciation across the community of the value of wild and scenic rivers, and the need to retain water to maintain river ecosystems and wetlands and meet recreational needs. In NSW, river management committees have been established to advise the Minister on equitable allocations of waters. The current estimate of the annual amount of water diverted from rivers is 11,562 GL/yr or 44% of the estimated divertible yield of 26,346 GL (Australian Natural Resources Atlas 2001).

Most of the developed resources are in south-eastern Australia, particularly the Murray-Darling Basin. In this region development of surface waters was at 51% of the total resource in 1985 (Table 11.1) and increased to 60% in 1995 when the Ministerial Council agreed on *The Cap*[1]. The aim of the Cap is to restrain diversions. New irrigation schemes can proceed with water gained through improved water use efficiency or the purchase of water from existing developments (MDBC, 2000). Under recent State legislations, such as the NSW Water Management Bill 2000, water is a tradeable commodity and not tied to land title.

**Water storage**

In Australia, some 447 large dams, which store about 79,000 GL of water, have been constructed to supply urban, irrigation and hydro-electric power users, and to provide flood mitigation. In addition there are several million farm-dams with a capacity to store 9% of the total water (Australian Natural Resources Atlas, 2001). Table 11.2 indicates the major storages for irrigation in Australia.

***Water Quality***

The key indicators of water quality entering or leaving irrigation areas are salinity, turbidity, dissolved nutrients, pH, faecal coliform and chemical residues. The National Land and Water Resources Audit (2001) revealed that less than one-third of the river systems in Australia are being monitored. The indications from available data summarised by the Audit suggest water quality guidelines for salinity, nutrients or turbidity were exceeded in 65 river basins. In 43 river basins (61% of those assessed) nutrients were excessive, in 41 rivers turbidity loads were excessive, and in 24 basins, mainly in the Murray-Darling Basin and the south-west coast regions, salinity levels were exceeded. In some basins, trends were available which indicated increasing turbidity, total phosphorus and salinity and decreasing pH. Further monitoring of these

[1] The CAP – 'that volume of water that would have been diverted (from New South Wales, Victorian and South Australian rivers within the Murray-Darling Basin) under the 1993/94 levels of development.'

indicators is required to detect unacceptable levels of sewage and industrial effluents from populated areas and salinity and eutrophication from agricultural activities.

The presence of nutrients, particularly nitrogen and phosphorus, from these sources in the water supplies encourages the prolific growth of algae, which exhausts the water's oxygen supply and kills other aquatic life. Many of the algal blooms, especially blue-green algal blooms, are highly toxic to livestock and to humans. The occurrence is greater in still water, particularly in summer months (Anon., 1992).

Salinity affects two main areas of the country. In southern Australia clearing of the natural vegetation has been followed by a rise in the water table levels (Colclough, 1973) with a consequent increase in the discharge of groundwater to river flow. As the groundwater has a naturally high salt content, both the soil and the surface water have been adversely affected. More than four million hectares of land have been rendered sterile and difficult to till due to dryland salinity resulting from poor land use (Anon., 1982). By 2050 over 12 million hectares of land are estimated to be salt-affected (Cox, 2001).

Table 11.2 Major water storages in mainland Australia for irrigation (adapted from Anon., 1986)

| State | Name | Location | Gross capacity (thousand ML) | Year completed[a] |
|---|---|---|---|---|
| Queensland | Beardmore | Balonne River | 101 | 1972 |
| | Fairbairn | Nogoa River | 1440 | 1972 |
| | Glenlyon | Pike Creek | 254 | 1976 |
| | Leslie | Sandy Creek | 108 | 1985 |
| | Fred Haigh | Kolan River | 586 | 1975 |
| | Tinaroo Falls | Barron River | 407 | 1958 |
| | Wuruma | Nogo River | 194 | 1968 |
| | Boondooma | Boyne River | 212 | 1983 |
| | Burdekin | Burdekin River | 186 | 1986 |
| New South Wales | Eucumbene | Eucumbene | 4807 | 1958 |
| | Blowering | Tumut River | 1628 | 1968 |
| | Burrinjuck | Murrumbidgee River | 1026 | 1927 (1956) |
| | Copeton | Gwydir River | 1364 | 1976 |
| | Glenbawn | Hunter River | 362 | 1958 |
| | Hume | Murray River | 3038 | 1936 (1961) |
| | Burrendong | Macquarie River | 1677 | 1967 |
| | Keepit | Namoi River | 423 | 1960 |
| | Wyangala | Lachlan River | 1218 | 1936 (1971) |
| | Menindee Lakes | Darling River | 1794 | 1960 |
| | Talbingo | Tumut River | 921 | 1971 |
| | Jindabyne | Snowy River | 688 | 1967 |
| | Lake Victoria | Murray River | 680 | 1928 |
| | Windamere | Cudgegong River | 368 | 1984 |
| | Glennies Creek | Hunter Valley | 284 | 1983 |
| | Tantangara | Murrumbidgee River | 254 | 1960 |
| | Lake Brewster | Lachlan River | 150 | 1952 |
| Victoria | Cairn Curran | Lodden River | 149 | 1958 |
| | Dartmouth | Mitta Mitta River | 4000 | 1979 |
| | Eildon | Upper Goulburn River | 3392 | 1927 (1958) |
| | Thomson | Thomson River | 1175 | 1984 |

| | | | | |
|---|---|---|---|---|
| | Eppaloch | Campaspe River | 312 | 1964 |
| | Glenmaggie | Macalister River | 190 | 1927 (1958) |
| | Mokoan | Winton Swamp, Benalla | 365 | 1971 |
| | Waranga | Rushworth | 411 | 1910 |
| | Yarrawong | Murray River | 117 | 1939 |
| | Toolondo | Natural depression, Horsham | 107 | 1952 (1960) |
| Western Australia | Ord (Lake Argyle) | Ord River | 10,760 | 1971 (1990') |
| | Wellington | Collie River | 185 | 1933 (1944, 1960) |

[a] Dates in brackets indicate date of completion of enlargement of the storage

Salinity affects two main areas of the country. In southern Australia clearing of the natural vegetation has been followed by a rise in the water table levels (Colclough, 1973) with a consequent increase in the discharge of groundwater to river flow. As the groundwater has a naturally high salt content, both the soil and the surface water have been adversely affected. More than four million hectares of land have been rendered sterile and difficult to till due to dryland salinity resulting from poor land use (Anon., 1982). By 2050 over 12 million hectares of land are estimated to be salt-affected (Cox, 2001).

In south-eastern Australia, salinity problems are of concern in the Murray Valley, where the salt content of the river is less than 30 mg/L total dissolved salts in the upper reaches but increases progressively downstream. The salts are predominantly sodium, calcium and magnesium chlorides and sulphates.

The increases in river salinity are linked to man-induced changes to the hydrological cycle. At Waikerie in South Australia, for example, salinity levels in the Murray River are about 15 times those at Jingellic, NSW (Anon., 1986; 1992) but the variations reflect river flows (Figure 11.2). This increase in the salinity of the Murray is caused by additions of more saline water from tributaries. The groundwater is recharged in tree-cleared catchments and, together with contributions from channel seepage and irrigation water, there is a resulting rise in the water table and increased drainage of saline ground water into the river (Blackburn, 1978).

The salinity of many major rivers is expected to increase (NLWRA, 2001). The consequences of this include deterioration in soil structure, environmental degradation, reduced crop production, damage to infrastructures such as roads and buildings, and for cities such as Adelaide unacceptable drinking water. In an attempt to halt or reverse the increases in river salinity, in-river and end-of-valley targets are being defined. One of the first was the MDBC guideline that the salinity of the Murray River should be below 800 EC-Units (0.8 dS) 95% of the time (MDBC, 2000b). The most recent records indicate the amount of salt being returned to the Murrumbidgee River system from the region east of Griffith is some 3700 to 5300 t/year (Table 11.3).

The development of the salt problem in an irrigation area is evidenced by the annual salt balance in the Murrumbidgee Irrigation Area (Table 11.3). The amount of salt in this and other irrigation areas could increase as more irrigators install recycling systems to save water and comply with environmental requirements. The increased retention of salt in the irrigation regions is likely to impact adversely on agricultural productivity. Reduction in the amount of salt returned to rivers will require careful management of salt within irrigation areas.

**Groundwater Supplies**
About 80% of Australia is significantly dependent, directly or indirectly, on ground water supplies (Anon., 1986). The estimated annual recharge is 72 million ML. Annual groundwater use is estimated at 2.5 million ML which represents 3.5% of the annual recharge and 18% of Australia's total water use. An estimated 72% or 25,780 GL of groundwater in Australia is regarded as being suitable for potable water, for stock and domestic use and for the irrigation of a range of crops able to tolerate up to 1500 g/L of total dissolved solids (Australian National Resources Atlas, 2001).

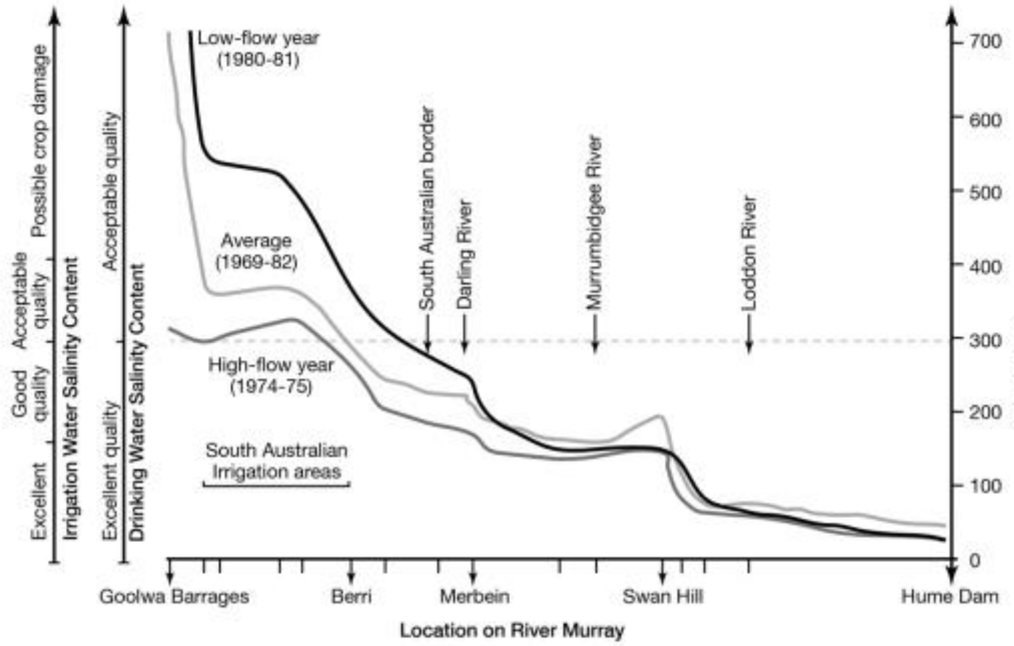


Figure 11.2 Influence of annual flow and distance from source on the salinity of the Murray River (MDBC, 2000)

Table 11.3 Salt balance in the Murrumbidgee Irrigation Area (data provided by Murrumbidgee Irrigation Limited, 2002)

| | Irrigation Season | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1998-1999 | | 1999-2000 | | 2000-2001 | | 2001-2002 | |
| Salt source and sinks | Flow (ML) | Salt Load (tonnes) | Flow (ML) | Salt Load (tonnes) | Flow (ML) | Salt Load (tonnes) | Flow (ML) | Salt Load (tonnes) |
| Diversions into the eastern MIA* | 1036169 | 86848 | 818496 | 70068 | 1048053 | 83795 | 1141607 | 76441 |
| Outflow to the western MIA** | 156000 | 46494 | 117000 | 41400 | 122000 | 40200 | 118520 | 28332 |
| | 19594 | 4113 | 19810 | 5171 | 22660 | 5355 | 17620 | 3698 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Drainage back to the river | | | | | | | | |
| | 860575 | 36241 | 681686 | 23497 | 903393 | 38240 | 1005467 | 44411 |
| Remaining in the eastern MIA | | | | | | | | |

*Includes Yanco and Mirrool Irrigation Areas and Tabbita and Benerembah Irrigation Districts (total farm area: 218,800 ha)
**Wah Wah Irrigation District (total farm area: 261,640 ha)

There are three main sources of ground water[2]:

- *shallow, unconsolidated sediments*, which are found in the principal river and lake systems and as coastal dunes, deltas and narrow shoreline deposits. Since 1957, use has been made of the good quality groundwater resources of the inland drainage systems of New South Wales, such as the alluvium of the Lachlan, Macquarie and Murrumbidgee valleys. In central Australia, this good source of quality groundwater (in unconsolidated sediment) is rare because of lower rainfall and higher evaporation rates.

  In Queensland, the sugar industry has drawn on the extensive groundwater resources of the Burdekin delta to such an extent that it has become necessary to use surface water to artificially recharge the aquifers. In 1970, for example, 33,800 ha of cane were under irrigation, requiring an estimated 3.2 ML/ha of supplementary irrigation water. Some 350,000 ML of river water were pumped to artificially recharge the aquifers.
- *sedimentary basins* (Figure 11.3) which contain at least one major aquifer system. In many cases the water is unsuitable for irrigation because of the high concentrations of sodium relative to the other cations, particularly calcium and magnesium. This is especially so in the Great Artesian Basin, which occupies about 23% of the landmass. These waters, however, are an important source of water for domestic and livestock purposes.
- *fractured rocks* are an important source of water particularly in the highlands of the southeast mainland, and in Tasmania, parts of South Australia, central Australia and Western Australia. These aquifers usually yield small quantities of water, the quality of which may vary considerably over short distances. The quality is generally good over northern and eastern Australia but poor over much of South Australia, the southern portion of the Northern Territory and southwest part of Western Australia. In the latter areas this variability and poor quality of groundwater are due largely to the low rainfall and high evaporation, coupled with low permeability of the strata.

**Conjunctive Use of Surface and Groundwater**

The utilisation of water resources in most areas of Australia has tended to concentrate on either ground or surface water. However, it has become increasingly necessary to

[2] Groundwater management is also the responsibility of the State governments but, in the national interest, the Commonwealth is involved. Just as surface waters are under threat from pollution and over-exploitation, groundwaters are also at risk and the Commonwealth provides a leadership and coordination role for policy reforms (AFFA, 2001).

utilise all water resources of a region in combination (Table 11.4). The relative merits of surface storage and groundwater storage are presented in Table 11.5.

In Australia, the level of development of water resources has been such that combined use of these resources has not been required to any extent. As the degree of overall development proceeds and as the value of water rises, there is increasing pressure for greater amounts of water to be supplied at higher levels of reliability.

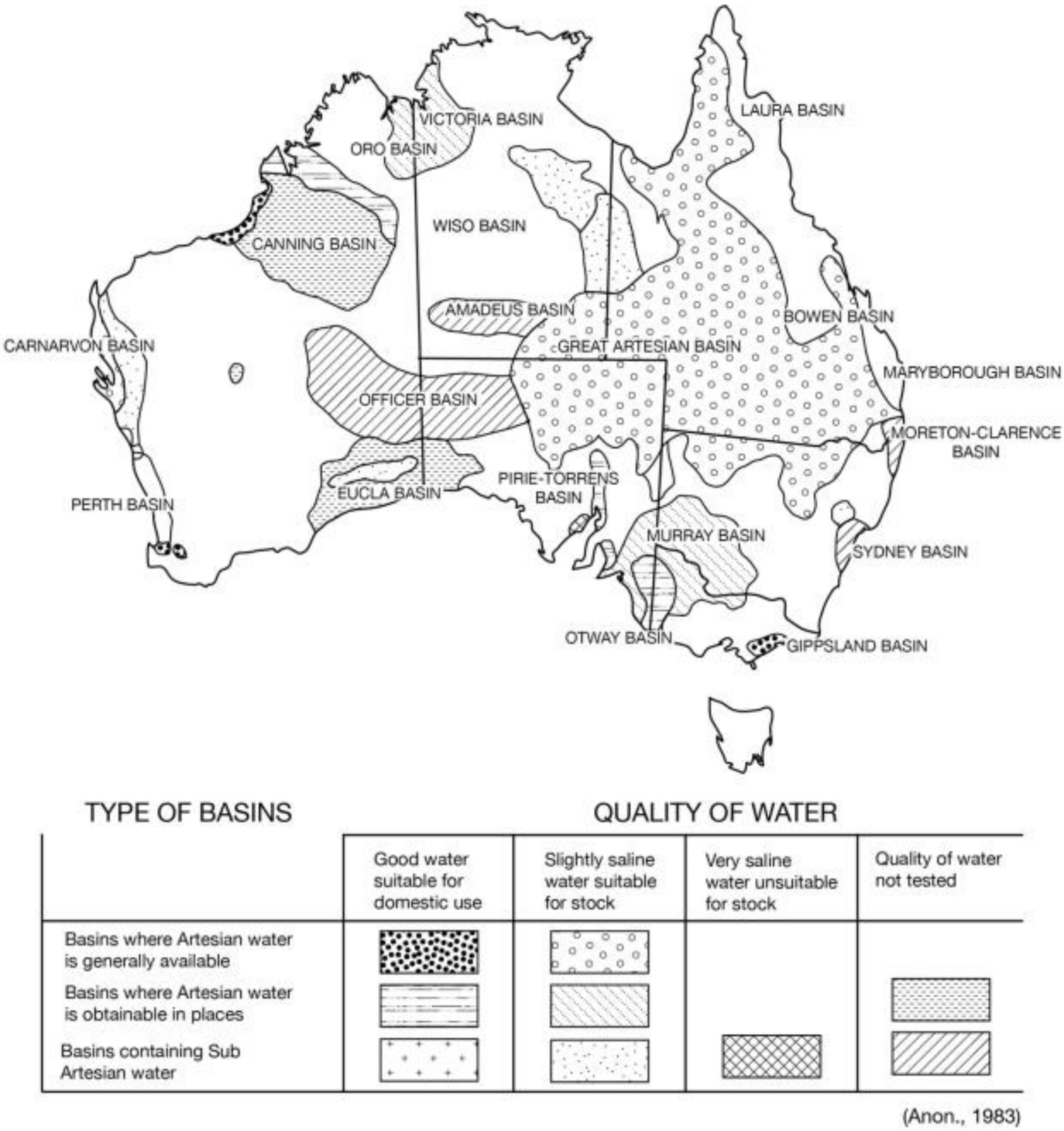


Figure 11.3 The sedimentary basins of Australia (Anon., 1983)

Table 11.4. Area irrigated by various sources of water, 1989-90 (adapted from Anon, 1992)

| | Area (thousand ha) | | | | | |
|---|---|---|---|---|---|---|
| | NSW | Vic | Qld | SA | WA+Tas | Aust (a) |
| Surface water | | | | | | |
| From State schemes | 399.2 | 418.4 | 89.6 | 16.9 | 16.7 | 940.9 |
| From other schemes | 351.9 | 60.0 | 65.5 | 19.6 | 18.4 | 515.7 |
| Direct from lakes, rivers, etc | | | | | | |
| From farm dams | 19.0 | 25.4 | 40.9 | 4.6 | 28.4 | 118.2 |
| Total surface water | 770.0 | 503.8 | 195.9 | 41.1 | 63.5 | 1574.9 |
| | | | | | | |
| Underground water | 48.5 | 19.8 | 115.8 | 56.0 | 8.9 | 249.8 |
| Town or country Reticulated water | 1.3 | 2.8 | 0.4 | 1.9 | 0.7 | 7.1 |
| Total all water sources | 819.8 | 526.4 | 312.1 | 99.0 | 73.1 | 1831.7 |

(a) Includes data for ACT and Northern Territory

Table 11.5. A comparison of the characteristics of surface storage and ground-water storage for irrigation

| | Surface storage | Groundwater storage |
|---|---|---|
| Capacity | Small | Large |
| Recharge response | Rapid | Slow |
| Cost -capital | High | Low |
| - operating | Variable[a] | high[b] |
| Evaporation losses[c] | High | low |

[a] high costs with pumping for sprinkler irrigation
[b] when pumping required
[c] losses from storage only

In the Namoi Valley, NSW, and in the Burdekin and Callide Valleys in Queensland, irrigating from groundwater sources has severely lowered the water table. The conjunctive use of different sources of water is used to overcome this problem. Surface sources are used during periods of river flow, thereby also allowing recharge of groundwaters for use during the remainder of the time. Over-commitment of the ground water resources in some irrigation districts has forced State authorities to reduce allocations to as little as 20% of the licence allocation.

A further example of conjunctive use is where the groundwater source by itself is unsuitable for irrigation because of its high salt content. If mixed at an appropriate dilution with high-quality surface water, the resultant water is then suitable for irrigating crops and pastures.

*Control of Water Resources*

Australia's water resources are managed by about 800 irrigation authorities, metropolitan water boards, local government councils and private individuals. State authorities dominate the assessment and control of water resources because, under the Australian Constitution, primary responsibility for water management rests with individual state governments. The Australian Government participates indirectly, through financial assistance, with policy bodies such as the Murray Darling Basin Ministerial Council and research and development corporations such as Land and Water Australia and the CSIRO, and is directly involved through the coordination or operation of interstate projects.

In recognition of the important environment problems facing the Murray-Darling Basin, the governments of South Australia, Victoria, New South Wales and Queensland agreed in 1985 to form the Murray Darling Basin Ministerial Council. The Council has a charter to promote and coordinate effective planning and management for the equitable, efficient and sustainable use of the water, land and environmental resources of the Basin (Blackmore, 1989). The Murray-Darling Basin Commission operates as the executive committee of the Council.

The proper management of water resources is essential to the maintenance of both quantity and quality of supplies and to the ecological balance of the environment in general. Since water is an agent of erosion and deposition, the consequences of its mismanagement can be very damaging.

## METHODS OF IRRIGATION

The methods of irrigation depend on water availability, the method of supply, the crop to be grown, the region in which it takes place and the personal preference. The main systems comprise surface and pressurised systems such as sprinkler, drip (trickle) and micro-irrigation, the most important for agricultural field crops being surface irrigation. Sprinkler, drip and micro-irrigation are confined largely to horticultural crops. However, use of sprinkler and drip irrigation systems with vegetables and some field crops is increasing. Use of drip and micro-irrigation systems in Australia have increased from 20,000 ha in 1981 to 59,700 ha in 1986 and 147,000 ha in 1991 (Bucks, 1995).

### Surface irrigation

Approximately 70% of the water used to irrigate field crops and pastures in Australia is surface irrigated, i.e. the water is distributed and delivered to plants across the soil surface. Several methods are used to distribute and apply water at on-farm level:

- in borders or bays, where water is confined between levee banks of soil; and
- in irrigation furrows.

*Border check*

In this method, the water is directed down the slope of the land between a system of low parallel banks called check banks (Figure 11.4). Under ideal conditions the rate of flooding is such that the water is uniformly absorbed by the soil as the sheet of water flows down the strip (border). This method is suited to land which is comparatively flat and has uniform slope. It is used on slopes ranging from 0.12% to 3%.

The check banks are formed by grading across the slope of the border, i.e. parallel to the contours and are then formed into the required slope and height by means of a grader or crowder. The banks should be low and wide to permit the crossing of farm machinery and to allow for cultivation so that full use is made of the land. The banks therefore should be of the order of 15 to 20 cm high and approximately one metre wide at the base.

The dimensions of the borders depend on a number of factors, including soil type, land slope, type of crop, depth of application and rate of supply of water into the border. Borders vary from 10 to 20 m wide and from 100 to 200 m in length. Narrow short borders are used on the steeper slopes and on coarse textured soils, in the latter case to move the water over the land quickly to avoid excessive deep-percolation losses. Where the land is flat or where the soils are heavy, wide, long borders can be used. Table 11.6 indicates the flow rates required to irrigate strips under different conditions.

To increase the efficiency of the operation, the borders must be graded in order to eliminate high spots, which will be under-watered, and low spots, which will be subject to ponding. To ensure uniformity of application, the steepest slope down the length of the border should not exceed twice the flattest slope. The use of laser-controlled land levelling has been a major advance. Fields can now be levelled to a near-perfect plane, allowing rapid and even application and removal of water (Barrett, 1985) and easy management.

*Contour check*

On relatively flat slope, the contour check method is used. In this system, check banks are laid out across the slope closely following the natural contours of the land. Water is diverted from the supply channel in to the highest point of each bay and held there until the whole bay is flooded. This method is used for the production of rice and also for pastures on heavy soils. It has been the principal method of irrigation in the Murrumbidgee Irrigation Area.

The minimum distance between banks must allow for the passage of cultivating and harvesting machinery. This is usually about 20 m. The contour intervals at which the banks are located are designed to keep the size of the bay in the range of 1.5 to 2.5 ha for pasture irrigation and 5.5 to 6.5 ha for rice. The most common contour interval is 7.5 cm for the slopes encountered. This may be reduced to 4 cm on flat ground but, where the ground slope is less than 0.04%, a border ditch system may be preferred. The contour interval may be as high as 15 cm on steep ground, but where the slope is steeper than 0.67%, a border check system should be used. It is particularly important in the culture of rice that the slope should not be too great because of the importance of the effect of water height on the degree of tillering of the crop. The number of tillers per plant is reduced if the permanent water is too deep. Under conditions of excessive slope, the need to maintain the top of the bay under permanent water results in the lower end of the bays being under excessive water.

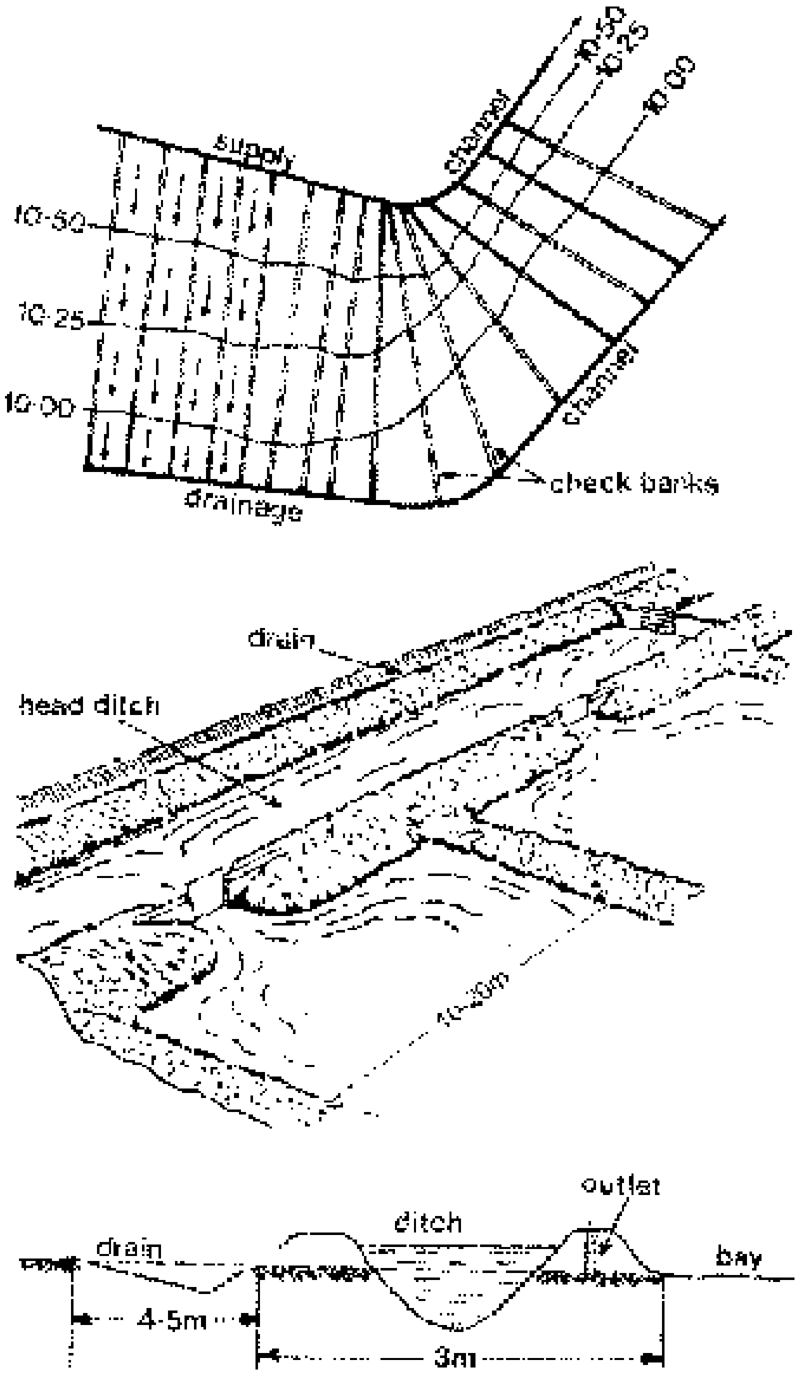


Figure 11.4 The border check method of irrigation (Water Resources Commission of New South Wales, 1978, unpublished).

Table 11.6. The relationship of soil, slope and application flow rate for border check irrigation.

| | | Dimensions of strip | | | |
|---|---|---|---|---|---|
| Soil | Slope (%) | Application (mm) | Width (m) | Length (m) | Quantity [a] (ML/day) |
| Coarse or sandy | 0.25 | 50 | 15 | 150 | 19.5 |
| | | 100 | 15 | 240 | 17.0 |
| | | 150 | 15 | 400 | 14.5 |
| | 1.00 | 50 | 12 | 90 | 6.5 |
| | | 100 | 12 | 150 | 6.0 |
| | | 150 | 12 | 270 | 6.0 |
| | 2.00 | 50 | 9 | 60 | 3.0 |
| | | 100 | 9 | 90 | 2.5 |
| | | 150 | 9 | 180 | 2.5 |
| Medium or loamy | 0.25 | 50 | 15 | 240 | 17.0 |
| | | 100 | 15 | 400 | 14.5 |
| | | 150 | 15 | 400 | 8.5 |
| | 1.00 | 50 | 12 | 150 | 6.0 |
| | | 100 | 12 | 300 | 6.0 |
| | | 150 | 12 | 400 | 6.0 |
| | 2.00 | 50 | 9 | 90 | 2.5 |
| | | 100 | 9 | 180 | 2.5 |
| | | 150 | 9 | 300 | 2.5 |
| Fine or clay | 0.25 | 50 | 15 | 400 | 10.0 |
| | | 100 | 15 | 400 | 10.0 |
| | | 150 | 15 | 400 | 3.5 |
| | 1.00 | 50 | 12 | 400 | 6.0 |
| | | 100 | 12 | 400 | 3.0 |
| | | 150 | 12 | 400 | 2.0 |
| | 2.00 | 50 | 9 | 200 | 2.5 |
| | | 100 | 9 | 400 | 2.5 |
| | | 150 | 9 | 400 | 1.5 |

[a] Figures are rounded to the nearest 0.5 ML

The banks should be about 30 cm high for pasture and at least 40 cm high for rice to enable deep water (25 cm) to be applied at the early pollen microspore stage of crop development. The deep water acts as a heat sink to protect the developing pollen from injury when night air temperature fall below 19°C (Williams and Angus, 1994; Lacy *et al*., 2001). It counteracts the effects of cool nights at that growth stage. The banks should be of the order of 3 m across the base and generally no more than 800 m long.

The advent of laser levelling, more efficient grading techniques and the need for better water control have led to a radical redesign of this method, with regular contour bays commonly being replaced by more uniform, rectangular bays.

Whilst it takes less labour to irrigate, the contour check systems will give inefficient irrigation and poor water control if used with rough grading, poor drainage, and in very large bays. It is unsuitable for permeable soils.

*Border Ditch*

The border ditch method is used on very flat land where drainage would be a problem if other methods were used. It is a modification of the border check method, but small ditches are used instead of the check banks. The earth from the ditches forms a small bank on each side of the ditch.

The ditches are run across the contours in the direction of maximum slope and may be up to 60 m apart. Water is usually supplied at the top of the bay in the same manner as for border check system.

The ditches are connected to the drainage system and low spots can be drained into the ditches at intervals down the bay. The bays are usually considerably larger than with border check, bay lengths of 450 m or more sometimes being used. It is a commonly used method for irrigated pastures in the Riverina, NSW.

*Furrow Irrigation*

Field crops such as cotton, maize, soybean, sorghum and some vegetables are grown as row crops and as such are usually furrow irrigated, the irrigation water being applied in furrows between rows (Figure 11.5). When irrigation water is sent down the furrows, part is absorbed by the soil and penetrates to the root zone of the growing plants. Cultivating the furrows controls weed growth and keeps the soil loose. This method may be used on all soil types except coarse or sandy soils. A benefit of this method is that only one-fifth to one-half of the total soil surface is flooded, thus reducing evaporation losses and making it possible to cultivate the soil sooner after watering.

Water is usually supplied from a head ditch using irrigation siphon tubes and distributed over the field in inter-row furrows (Figure 11.5). The flow rate through siphons into furrows depends on the head difference between the channel water level and the siphon outlet or the water level in the furrow if the outlet is submerged. The flow rates through commonly used irrigation polyethylene siphons are given in Table 11.7. Ideally, the flow rate down the furrow will be sufficient to supply the plant requirements, with a minimal loss of water through drainage below the root zone and past the end of the furrow.

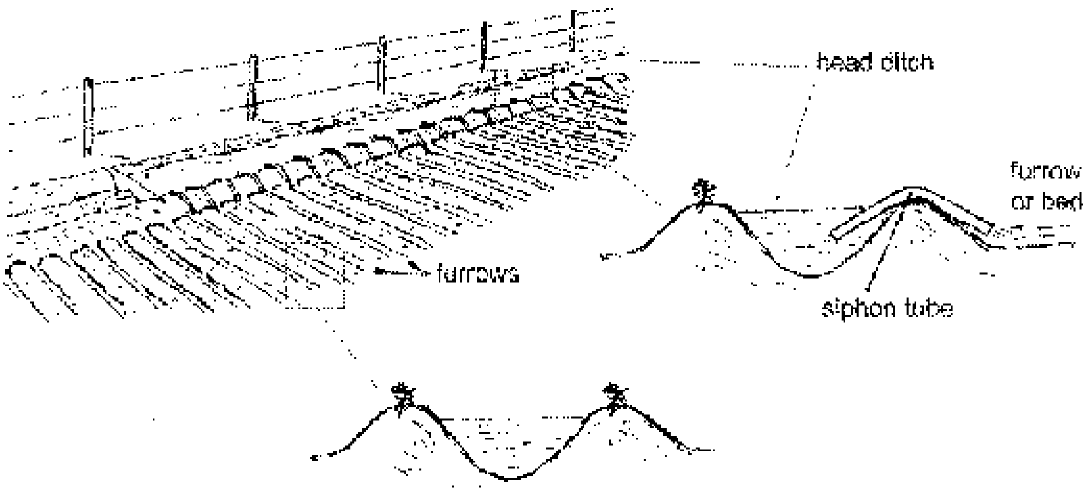


Figure 11.5 Furrow irrigation (after Water Resources Commission of New South Wales, 1978, unpublished).

Table 11.7. Flow rates through siphons (3.5 m long) commonly used with furrow irrigation (Tennakoon and Milroy, 1999).

| | Flow rate (L/s) | | |
|---|---|---|---|
| Head cm | Siphon diameter | | |
| | 50 mm | 55 mm | 60 mm |
| 8 | 1.01 | 1.32 | 1.68 |
| 10 | 1.14 | 1.50 | 1.90 |
| 12 | 1.26 | 1.66 | 2.10 |
| 14 | 1.37 | 1.82 | 2.28 |
| 16 | 1.47 | 1.96 | 2.46 |
| 18 | 1.57 | 2.09 | 2.62 |
| 20 | 1.66 | 2.22 | 2.78 |
| 22 | 1.75 | 2.35 | 2.93 |
| 24 | 1.84 | 2.47 | 3.07 |
| 26 | 1.92 | 2.58 | 3.21 |
| 28 | 2.00 | 2.69 | 3.34 |
| 30 | 2.08 | 2.80 | 3.47 |
| 32 | 2.16 | 2.91 | 3.60 |
| 34 | 2.23 | 3.01 | 3.72 |
| 36 | 2.30 | 3.11 | 3.84 |
| 38 | 2.37 | 3.21 | 3.95 |
| 40 | 2.44 | 3.30 | 4.07 |

The layout of the furrows depends on the slope of the land to be irrigated. On gently sloping land (0.05 to 1%) straight furrows are used, but where the slope is steeper (even up to 5%), contour furrows are used. In the latter case, the furrows are formed across the slope, sufficiently off the true contours to give the required gradient for steady flow of irrigation water down the furrow. Contour furrows are used to some extent in Queensland for irrigation of tobacco, vegetable crops and orchards. Most furrow-irrigated paddocks in irrigation areas in the Murray Darling Basin are now graded using laser levelling technology. Land grading has created regular shaped paddocks and vastly improved the water management of furrow irrigated lands.

On sloping land, erosion of furrows can be a serious problem and careful control of the irrigation stream is required. The non-erosive flow rate depends largely on the slope on which furrows are to be laid. This is given by the approximate relationship

$$\text{Non-erosive flow rate (L/minute)} = 36/\text{slope (\%)}$$

Poor filtration and faulty design are the main courses of trouble and extra work. Where filtration is poor, blockages nearly always result, mainly from grit, algae and slimes or iron oxide. Algae are the most likely sources of trouble, even when not visible, as they can be present in sufficient quantity to cause frequent filter blockage. The nature of the material is such that blockage occurs over the entire screen, causing complete stoppage. Control of algae is achieved by spraying copper sulphate, at the rate of one part per million over the entire water surface, by chlorination of water if iron concentration is greater than 1 mg/L and, where possible, excluding light from the storage. Iron oxide can be removed by aeration of the holding tank prior to filtration (Ingram and Mazor, 1993).

As drip irrigation requires less water per hectare it allows small deliveries from bores and soaks to be used to irrigate areas for which the supply rate is otherwise inadequate. This method of irrigation is largely confined to horticultural crops, although the commercial use for row crops such as tomatoes and cotton is increasing (Barrett, 1985).

**Micro-irrigation**

Classification of micro-irrigation systems is rather ambiguous in the literature as drip irrigation is sometimes classified as a micro-irrigation system. Here distinction is made between drip irrigation systems and micro-irrigation systems, which comprise micro jets and mini-sprinklers which operate at low pressure at 105 to 150 kPa (Murphy, 1991). Lateral water supply lines are usually of polythene laid along the rows of crop. Water is applied with micro jets in about 3 to 4 metre-diameter circles along the crop line at a rate of 1 to 2 L/minute, whereas mini-sprinklers project water in circles up to about 10 m in diameter at about 2 to 4 L/minute.

In comparison with drip irrigation a greater area of soil is wetted by micro-irrigation, thus giving a better coverage of the root zone of trees and vines, particularly on light-textured soils (Murphy, 1991). These irrigation systems do not require extensive filtration and chemical treatment of water as needed by drip irrigation systems. More frequent irrigation may be required, however, since there is less water storage in the soil.

## SOIL AND IRRIGATION

The successful production of irrigated crops depends on a range of factors, many of which are directly related to the soil. In much of the irrigation practised in Australia, crops are grown in areas where water is the limiting factor to crop production. Irrigation therefore tends to produce an artificial environment in the soil compared to its natural state. The soil water levels are higher with the irrigation, and the relationship[3] between the soil and water becomes more critical.

Irrigation may also affect the characteristics of the soil depending on the nature of the soil and the quality of the water used for irrigation. Whether the soil is suitable or not for irrigation depends on a number of factors including:

- the ability of the soil to readily absorb water;
- the ability of the soil to hold adequate quantities of water to support crop growth;
- the soil's ability to freely drain;
- the susceptibility of the soil to erosion;
- the fertility status of the surface soil;
- the reaction of the soil to salt contained in the irrigation water;
- the relationship with the adjoining soils or micro-relief features; and
- the depth of the root zone.

**Soil properties affecting irrigation requirements**

The irrigation requirements of a soil depend mainly on several properties of the soil profile. Some of these properties relate directly to the immediate profile situation at the point of water application, some relate to associations within the micro-relief, while others are chemical properties which affects the physical condition of the soil. The physical properties also have considerable effect on the water-holding capacity of the soil.

*Effect of texture*

Texture can be defined as the particle size distribution in soil, that is, the proportions of sand, silt and clay (Table 11.10). In the field, estimations of texture can be obtained by a hand test. In all, 19 textural classes are recognised, ranging from sand, which has less than 5% clay, to heavy clay, which can contain 50 % or more of clay. In the field, coarser

textured soils (i.e. sand with large particle size) have higher infiltration rates than clay and drain more freely. Furthermore, the amount of water held in soils at field capacity and permanent wilting point increases as the clay content increases. The plant available water capacity of the soil is also influenced by texture up to the point where the soil

[3] About 48 hours after an irrigation some of the water in the soil drains out or moves to drier areas and arrives at a soil water status called field capacity (FC) or drained upper limit. When the soil has reached FC, no more water will be drained out from the system. However, plants can absorb water from the soil at FC. As the water is taken up by the plants and evaporates from the soil surface, water content will decline and reach a critical level where plants cannot absorb further water from the soil and wilt permanently. Water content at this critical level is called permanent wilting point (PWP) or lower limit. The amount of water that is released from FC to PWP is called plant available water (PAW). The amount of PAW varies with the soil type.

contains about 25% clay. Up to that clay content the plant available water-holding capacity increases with clay content and above that level the available-water holding capacity is somewhat reduced (Table 11.11, Figure 11.6). Permeability and vertical movement of water downwards also decreases as texture becomes finer, i.e. as the soil grades from course texture to fine texture.

Table 11.10 International standard particle diameters for textural separates

| Textural separate | Particle diameter (mm) |
|---|---|
| Gravel | Above 2.00 |
| Coarse sand | 2.00-0.20 |
| Fine sand | 0.20-0.02 |
| Silt | 0.02-0.002 |
| Clay | Below 0.002 |

Table 11.11 Influence of texture on soil water characteristics (Salter and Williams, 1965)

| Textural class | Field capacity (%$H_2O$) | Permanent wilting point (%$H_2O$) | Available water-holding capacity (per 30 cm depth) | |
|---|---|---|---|---|
| | | | (%) | (mm) |
| Sand | 6.7 | 1.8 | 4.9 | 20 |
| Loam | 32.2 | 11.8 | 20.4 | 63 |
| Clay | 39.4 | 22.1 | 17.3 | 48 |

The factors which affect the intake of water and its movement through the soil are the pore size distribution, adhesion of water to soil particles, and gravity. Pore size distribution can be determined from the texture. The adhesion of water to the particles affects both infiltration and transmission of water in the soil. Gravity also contributes to downward vertical movement of water.

In soils of uniform texture, sands have a greater proportion of large pores (>0.02 mm diameter) and are free draining. Infiltration into these soils is rapid and easy and the water is not firmly held. In a uniform clay soil, there is a greater proportion of fine pores (<0.002 mm diameter). Infiltration is slow and the water is firmly held by adhesion, so that movement downwards is slow and lateral movement is more significant. Gravity has an effect on the drainage of sands, so furrows need to be more closely spaced than in clay soils where furrow irrigation is practised (Figure 11.7).

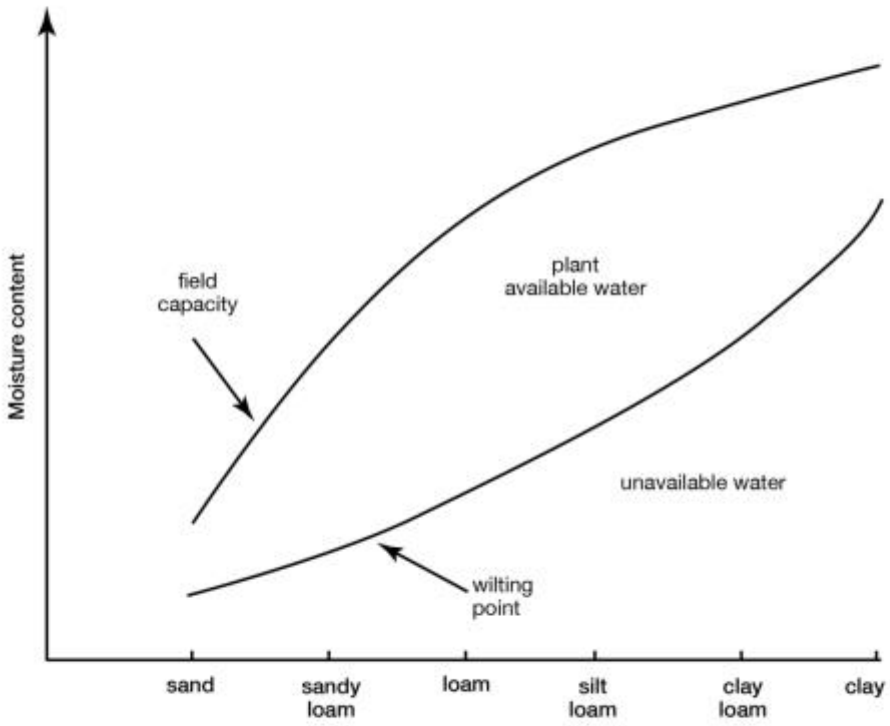


Figure 11.6 Water holding capacities of different textured soils (adapted from Brady, 1984)

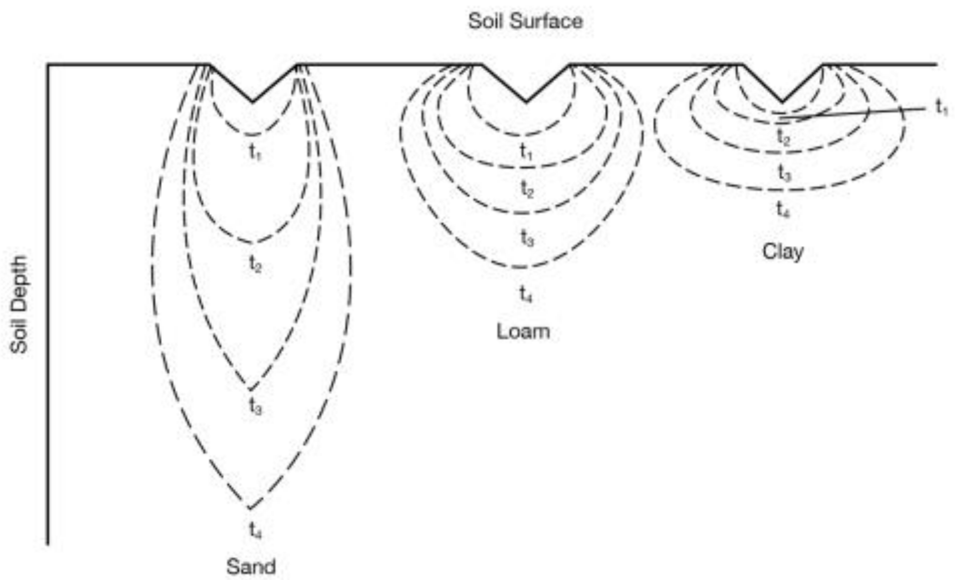


Figure 11.7 Representation of water penetration from furrows with time (t)

Under field conditions many irrigated soils are not uniform. Texture changes from horizon to horizon and there is a substantial range of pore sizes which affect water movement through the soil profile. Hence, drainage patterns will not be exactly as shown in Figure 11.7. Clay content tends to increase with depth down the profile and the downward movement of water slows as a result. The ability of a soil to transmit water through the profile is known as its permeability.

Water-holding characteristics also change from horizon to horizon depending on the texture. Both field capacity and permanent wilting point change throughout the profile. Depending on this, the amount of irrigation water applied and the irrigation interval will also vary depending on the water-holding capacity of the soil. For example, crops grown on sandhill soils at Berrigan, New South Wales, require irrigation every 3 days in mid- summer as against every 7 days on loam soils nearby.

While the amount of water held in the soil at both field capacity and permanent wilting point increases as the clay content increases, that is, as the texture becomes finer, it can be seen from Table 11.11 that the greatest volume of available water is held by the loam which can be regarded as the soil of medium texture. The amount of water held in a 30 cm depth of loam soil is equivalent to 63 mm compared to 48 mm in the same depth of clay soil and 20 mm in a sand. Normally when 50% of the PAW is used up by crops they begin to suffer yield losses. This means that if a crop has an effective root zone depth of 30 cm and is using water at the rate of 4 mm per day under peak demand, the plants would suffer water deficit stress after about 3 days in the sand, 6 days in the clay and 8 days in the loam.

Two physical forces, cohesion and adhesion, are responsible for the way water moves through soil in response to gravity. *Cohesion*, the force holding water molecules together, is important in saturated soil conditions. *Adhesion*, also called tension or suction, is the force holding the water film to soil particles. It is important in unsaturated soil conditions which operate after a soil has been irrigated and while it drains. Where a soil contains significant amounts of clay, adhesion becomes more important in slowing water movement down the profile.

Texture may be modified either by cementing agents such as silica, calcium carbonate, oxides of ion and aluminium, and humus, or by compaction due to cultivation, to the extent that a cemented or compacted layer is formed within the profile. The compacted layer does not transmit water as rapidly as the soil layers above it. As a result, the rate at which water moves through the soil will be determined by the transmission rate of the compacted layer. In turn, the infiltration rate of the soil will be affected. In extreme cases the subsoil may never attain field capacity because of the very slow water movement though the restrictive upper layers of soil. Under irrigation, affected soils show shallow water penetration, thus restricting soil water reserves and root development, and inducing water stress in summer. Surface waterlogging can also be caused by excessive irrigation or by rain following the irrigation.

### *Effect of Structure*

Soil structure is the organisation or arrangement of individual particles into larger groupings called peds. The proportion of the soil mass occupied by the peds and their geometry contribute towards the permeability of the soil. Therefore, if the soil is made up of a major proportion of large, regularly shaped peds which intermesh to a tight mass, the soil will not be as permeable as it would be if the peds were smaller and rounder and had more pores and channels in the soil through which irrigation water could more freely move.

It is important to consider the influence of structure in soils of the same textural class. For example, a well-structured clay soil will be more permeable than one which is poorly structured. The well-structured clay soil can exhibit water infiltration and transmission characteristics similar to those of a coarser soil, i.e. a loam. For irrigation, the stability of the structure is also important. The topsoil will be required to withstand the degrading effects of both extensive land forming and seedbed preparation for irrigated crops. Where the structure is readily broken down, the surface may compact easily or crust, and water entry and movement in the soil can be reduced.

In clay soils, the nature of the clay is also another important factor affecting both infiltration and transmission of water. In those soils, where swelling and shrinking of the clay is concerned, pore space and permeability change while the soils are wetting. Infiltration and transmission are both much affected because the swelling of the clay tends to reduce effective pore size. The water content of the soil during irrigation could well modify the effect of texture and structure. Macropore flow is most important in clay soils since there is little matrix (micropore) flow.

The nature of the clay mineral affects the water characteristics of the irrigated soil. In the Vertosols (cracking clay soils) of northern New South Wales and southern Queensland, the drying out of the profile produces extensive vertical cracking together with the formation of the self-mulching surface. These vertical cracks can be several metres deep. The irrigation of the soil in the dry condition is accompanied by high initial infiltration rates, and the soil is capable of taking in large amounts of water. The depth and size of the cracks can give direct access to the subsoil. As the cracks fill with water, their dimensions, and those of the pores, are reduced by expansion of the clay. This quickly reduces the absorption rate of water, so water application rates need to be adjusted. Cracking clay soils do not have to crack extensively to affect water intake. The soil can be self-mulching, with only fine cracks developing as the soil dries. Alternatively, the soil may have limited shrinkage in the surface layers. With extensively cracking soils, plant roots can be broken as cracking occurs, so that plants suffer a water deficit.

*Effect of Surface Condition*

The initial infiltration rate of a dry soil is governed by the condition of the soil surface. The condition can be natural or can be brought about by cultivation, although in this case the effect is usually only temporary. Under normal conditions, infiltration is controlled by texture and macropore (>0.6 mm) structure when surface irrigation methods are used. With sprinkler irrigation systems, the infiltration rate of the soil can be controlled by the application rate of the sprinklers, provided the application rate is less than the infiltration rate of the soil.

Infiltration of irrigation water is reduced when the surface soil sets hard. This condition may occur naturally when the soil dries or it may be induced as a crust. With a normally hard setting surface the problem can be overcome temporarily by cultivation. Alternatively, the infiltration rate gradually improves as the soil surface becomes moist. Where cultivation is used to overcome the effect of the hard setting surface, there is a mechanical degradation of surface soil structure and a progressive decrease in organic matter content. The surface soil can become more prone to slaking, where the finer particles can run together to form a crust. The crust acts as a barrier to water entry and the thickness and strength of the crust determines the amount of resistance offered to water entry. A crust is more likely to develop in finer soils, i.e. loams to clays, than in the coarser soils. In furrow irrigations, crusts can form from sediments washed from the sides of the furrows, thus reducing intake (Brown *et al*., 1988). Crusts can be formed also as the result of high levels of exchangeable sodium (Northcote and Skene, 1972) due to dispersion of the surface when wetted.

Major changes in soil structure need to occur before the soil's water balance is significantly affected (Cresswell *et al*., 1992). These changes are associated with the development of surface crusts and plough pans, the most common cause of both in irrigated soils being excessive cultivation.

The self-mulching surface is ideal for the absorption of irrigation water. As it is initially very open and porous it will readily accept water. Its principal disadvantage, however, is its association with the cracking clay soils, in which the smectitic clay swells on wetting. This swelling reduces the size of the non-capillary pores and also blocks the micropores. Both actions contribute to the reduction in infiltration rate and transmission of water.

A consideration of soil surface condition must also include the effect of ground cover on water entry into the soil. Generally, increased amounts of organic matter in the surface layers contribute to better structure and thus better infiltration (Table 11.12). Organic matter itself can contribute directly to increased water storage as it is able to absorb from two to six times its own weight of water. However, its contribution to more stable aggregates and improved structure can be considered as its more important role. Under sprinkler irrigation for example, a soil which contains adequate amounts of organic matter is more able to resist the battering action of the raindrops and retain its infiltration capacity over longer periods. The soil can therefore have a higher final infiltration rate.

As well as the effect of soil structure (resulting from increased organic matter from, for example, roots and leaf litter), surface cover helps to improve water penetration by slowing the velocity of flow over the soil surface and allowing more time for soakage. This effect is most common in border check and border ditch systems of irrigation with pasture. In furrow irrigation, the presence of weeds in the furrow acts in a similar way but, in this case, the free flow of water along the furrow is interrupted. Water penetration under these conditions is uneven, resulting in uneven watering of the crop with some areas in the soil becoming overwatered and other areas becoming underwatered.

Table 11.12 Effect of ground cover on infiltration (Wiesner, 1970).

| Type of cover | Infiltration rate (mm/hr) |
|---|---|
| Bare ground | |
| - crusted | 10 |
| - cultivated | 15 |
| Weed cover | 20 |
| Permanent pasture | |
| - heavily grazed | 30 |
| - moderately grazed | 40 |
| - lightly grazed | 50 |
| Old pasture (with heavy mulch) | 70 |

*Effects of Profile Characteristics*

The nature of strata underlying the root zone of an irrigated soil has an important effect on the behaviour of plants grown in that soil. Two important functions, infiltration and drainage, are, as previously described, dependent on texture and structure. The presence of a restricting layer of coarse material lower down the profile will affect or modify the behaviour of the soil in the root zone. Also to be considered is the depth at which this layer exists.

In the case of the restricting layer, the principal effect is the development of a perched water table. The restricting layer may be rock or clay or it may be a pan. The permeability of this layer, being much lower than that of the overlying soil, tends to restrict the downward movement of water, resulting in waterlogging. If this layer occurs within 2 or 3 m of the surface, continued irrigation can lead to surface waterlogging. In the Goulburn Valley of Victoria, Cockroft and Bakker (1966) found that waterlogging killed peach trees where a restricting layer existed less than 3 m down the profile. Waterlogging can be controlled by tile drainage below the root zone.

Subsoil waterlogging can occur where the soil overlies a porous stratum, which can act as an aquifer. The situation is worsened where the porous stratum itself overlies a cemented or impeding layer. This in turn can lead to an elevation of the water table, generally over a large area. Control in this case usually involves the construction of tube wells or bores into the aquifer and relies on pumping to lower the level of the water table. In the Murrumbidgee Irrigation Area of New South Wales many of the irrigated horticultural soils overlie prior stream gravels and sand beds which are tapped for deep drainage schemes. This has proven to be an effective control measure to lower water tables over considerable areas. Alternatively, where the strata are too permeable, it may lead to the exclusion of certain areas for particular irrigated crops such as rice (van der Lelij and Talsma, 1978). In the Darlington Point area, these prior stream aquifers have also been tapped to supply irrigation water to properties outside the irrigation areas.

The presence of sand beds does not automatically increase the transmission characteristics of the overlying soil. The rate of inflow and downward movement of water are determined by the conductivity of the least permeable layer. If, then, the surface soil is clay of low permeability, water moves slowly down to the sandy layer. The slow drainage in turn can cause surface waterlogging when the application rate exceeds the infiltration rate. The drainage water will enter the coarser sand only when there is sufficient build-up of water to overcome the effect of the greater suction in the clay soil. Alternatively, when a sand lens is interposed between a loam and an impermeable clay layer, drainage can be rapid until the water reaches the interface between the sand lens and clay. The rate of downward movement of the water then decreases to a value equal to the hydraulic conductivity of the clay. Under prolonged irrigation, the soil develops a water table in the sand lens. Eventually, both the root zone and the soil surface layers become waterlogged.

*Effect of Salting*

Salt-affected soils are widespread in Australia, representing about 33% of the total area (Northcote and Skene, 1972). Many of the larger irrigation schemes have been located on salt-affected soils. Prolonged irrigation in these areas has been accompanied by waterlogging and salinity problems (Beecher, 1991: Blackburn 1978; Mehanni, 1978; Muirhead, 1978). The problems that develop in salt-affected soils are salinity (high soluble salts) and sodicity (high exchangeable sodium levels).

*Soluble Salts*

The most commonly occurring soluble salts in soils are sodium chloride, calcium sulfate and the carbonates of calcium and magnesium. Bicarbonates may also be present but are frequently converted to the less soluble calcium and magnesium carbonates. The most common salt in Australian soils is sodium chloride. The concentration of soluble salts is normally reported as the electrical conductivity of a soil-water extract.

Northcote and Skene (1972) have described the criteria for salinity levels. Soils with sodium chloride contents above these criteria are not suitable for irrigation unless the salt can be leached from the root zone. The textural class of the soil and the method of irrigation are also important factors contributing to the accumulation of salt in the root zone. Finer soils, i.e. clay loams and clays, are more liable to salinisation than coarser soils, largely because the latter drain more freely and salt is removed more efficiently in the drainage water.

Saline soils usually occur in areas which receive salt transported from elsewhere. Water is the principal carrier, either as saline irrigation water or as ground water. However, the total amount of salt, its location in the profile, the salt content of the irrigation water, the method of irrigation, the ease of drainage and the depth to the water table all contribute to the development of a salting problem. A soil in which the salt occurs deeper than 2 m may not be in much danger of becoming saline. If, however, a saline water table is within 2 m of the soil surface the entire root zone may become saline due to upward movement of water from the water table. The evaporation from saline soils is no different in detail to that from non-saline soils (Russell, 1973). Evaporation from a saline soil leaves a saturated salt solution, which has a lower vapour pressure than a dilute solution and so takes longer to evaporate. Water continues to rise, carrying with it more salt solution, until eventually a salt encrustation develops. Once a salt area has been formed it tends to grow at the expense of surrounding soil, i.e. the salt tends to be concentrated in patches.

In free-draining soils, salt is leached below the root zone into the lower horizons. Therefore, the control of salinity in less permeable soils is achieved by controlling drainage water movement and preventing a shallow water table by the use of artificial drainage.

*Exchangeable Sodium*
The presence of large concentrations of exchangeable sodium in the soil poses problems under irrigation. In the heavy clays of the Riverine Plain, the high sodium content causes infiltration problems and interferes with seedling emergence. Both are the result of dispersion of the clay when the soil is irrigated and the development of a surface crust when the soil dries.

Germination and establishment of annual pasture species can be improved by the addition of gypsum in the irrigation water (Davidson and Quick, 1961). The effectiveness of the treatment depends on the amount of clay, the exchangeable sodium percentage (ESP) and evaporation conditions at sowing.

The critical value of exchangeable sodium is variable. The United States Salinity Laboratory has set the value at an ESP of 15, i.e. soils with an ESP of 15 or more show reduced permeability and poor infiltration. Under Australian conditions, however, dispersion and permeability problems occur in soils high in swelling clays at much lower ESP values. Emerson (1967) obtained dispersion of dry aggregates in water at an ESP of 7, while Northcote and Skene (1972) recommend an ESP of 6 as the lower limit. Low subsoil permeability and waterlogging in two soils (the Lemnos loam and Shepparton fine sandy loam) in the Goulburn Valley, Victoria, occurred at low ESP values (Bakker *et al*., 1973). However, in these cases it was suggested that the problems were caused by high exchangeable magnesium.

The importance of high levels of soluble salts and exchangeable ions in irrigated soils cannot be ignored. The soluble salts have a more direct effect on plant growth and production by making water less available to plants as a result of the increased osmotic pressure of the soil solution. The effect of the exchangeable sodium is more indirect as it changes the transmission characteristics of the topsoil or subsoil, which then reduces plant production due to waterlogging or secondary salinisation.

The rate of accumulation of salts in the root zone depends on their concentration in the applied water, the soil type and the extent of natural leaching provided by rainfall. The salinity status of the soil should be monitored regularly and extra water supplied periodically to leach the salts below the root zone (Barrett, 1985).

**Effect of Other Environmental Factors**
Factors other than profile characteristics also affect the water regime of irrigated soils. These include the slope and the micro-relief.

*Slope* The slope of the natural surface principally affects the form of irrigation used. On very gentle slopes (e.g. 0.1%), border check irrigation might be used, whereas on steeper slopes (e.g. 5%) sprinkler irrigation would generally be used. Surface slope and texture together will determine the infiltration rate of water and, in addition, affect lateral seepage and surface drainage.

*Micro-relief* In this context, the association of position in the micro-relief, elevation and slope all combine to affect drainage, lateral seepage, intake rate and the need for artificial drainage. Where these are also combined with the association of permeable soils on the elevated parts and soils of relatively poor permeability on the lower levels, waterlogging and salinity occur. Situations akin to this exist along the Murray Valley especially in South Australia (Northcote, 1949). It is interesting to note that soil associations frequently follow positions in the micro-relief, i.e. particular soils are nearly always in water-shedding situations while other soils are always in water-receiving positions. Micro-relief also influences the local microclimate, particularly with respect to frost. This can be particularly important with areas intended for horticultural crops.

## WATER MANAGEMENT

Crop yield is strongly correlated with the level of evapotranspiration so, in irrigated crop management, there is a need to match the supply of water to the needs of the crop.

As irrigation resources become increasingly regulated and expensive, more attention is being focused on improved layout and better water management. Barrett (1985) describes important management practices as:

- timing water application for maximum yields;
- timing deficits to minimise yield reductions when water shortages are inevitable, for example, slight water deficit stress in such crops as maize and sorghum can be imposed in the young vegetative stage without undue penalties in yield;
- avoiding over watering;
- increasing the uniformity of water application;
- beginning the season with adequate water in the root zone; and
- sprinkling at night to minimise evaporation and wind drift.

Sound water management involves applying the proper amount of water uniformly to the crop at the correct time. Numerous techniques are used to determine the schedule of irrigation. These include:

(a) *Visual crop symptoms*, such as wilting or colour changes. It is worth noting that plant growth is reduced when the relative turgidity of the plants declines below 90%, due largely to closure of the stomates which thereby restricts carbon dioxide entry into leaves for assimilation. Growth stops when visible wilting occurs. This means, therefore, that considerable productivity is lost before signs of deficit stress are apparent in the crop and the efficiency of water use is reduced.

(b) *Subjective sampling of soil water* down to at least 75 cm using a shovel, auger, soil sampler, or a soil moisture monitoring device. Surface soil conditions are unreliable for indicating moisture availability in the root zone.

(c) *Plant measurement* using pressure chambers to measure leaf water tension. This equipment requires trained operators for correct use and interpretation. Infrared thermometers to measure crop canopy temperatures ($T_F$) are also used commercially (Smith, 1986). Diagnosis of crop health is based on the deviation of the crop canopy temperature from the air temperature ($T_A$). In unstressed crops, the foliage is cooled by transpiration. However, as transpiration is reduced, the foliage becomes hotter and the foliage-air differential ($T_F$-$T_A$) is increased. A crop water stress index (CWSI) can then be determined by comparing $T_F$-$T_A$ of the crop with the differential of an unstressed crop (which represents the lower limit, LL) and of a completely stressed crop (the upper limit, UL) Thus,

$$CWSI = \frac{T_F - T_A - LL}{UL - LL}$$

CWSI varies from 0 (for an unstressed crop) to 1 (for a totally stressed crop). However, Stockle and Dugas (1992) have shown, using computer models, that the empirical CWSI gives a late indication of irrigation need, after some water stress has already developed. Thus the method may be unsuitable for use with water-sensitive crops.

(d) *Pan evaporation and the 'crop factor"* is a common method of determining irrigation scheduling and is therefore described in more detail.

Crops vary in their water requirements (Table 11.13) and for a particular crop the irrigation needs depend on the evaporative conditions operating at particular stages of growth. A crop which completely covers the ground and is well supplied with subsoil moisture transpires at approximately the same rate as water from a pan evaporimeter (Downey, 1971). However, a crop which covers only part of the ground transpires less water than that lost by pan evaporation, depending on the wetness of the surface soil. This is particularly important for row crops such as maize, sorghum and cotton because they cover relatively little ground when young, but there is almost complete ground coverage when they are mature. Therefore, compared to the standard evaporimeter, young row crops generally lose less water, but as they mature they transpire at about the same rate, particularly when the soil surface is dry (Downey, 1971).

This variation in transpiration has the effect of changing the crop factor (the amount of water transpired by a crop, which is estimated as some proportion of the evaporation from a standard pan evaporimeter). In some situations a constant crop factor can be used (e.g. pastures 0.9 x pan evaporation; citrus trees 0.5 x pan evaporation). However, for row crops, a constant crop factor will produce waterlogging in young crops and drought stress with maturing crops. Consequently, a useful guide is to multiply the pan evaporation by a crop factor of 0.2 at or just after sowing, 0.5 when there is 30% ground cover, and 0.9 for 60% ground cover to maturity. Under dry summer conditions of low humidity and strong winds, the crop factor will often reach 0.95 to 1.0 and may exceed 1.0 in crops such as lucerne and soybeans.

Table 11.13 Average consumptive use of water by crops

| Crop | Water use (mm) |
|---|---|
| Canola | 450 |
| Peanuts | 550 |
| Sorghum | 560 |
| Soybeans | 600 |
| Maize | 700 |
| Sunflower | 700 |
| Wheat | 600 |
| Cotton | 800 |
| Sugar cane | 900 |
| Rice | 1200 |

The amount of irrigation applied for efficient water use is dependent upon the depth of the root zone, which is defined as the depth of soil where 90% of the roots occur (Anon., 1974). In some cases this is determined by the depth of soil available to the plants, but more particularly by the crops being grown. According to species, plants can be classified as deep or shallow rooted (Table 11.14). The depth of the root zone will therefore influence the amount of irrigation water applied because of the need to avoid loss of water through deep percolation. Shallow-rooted crops require more frequent irrigations than deep-rooted species growing on the same soil.

The water requirements of the plant vary with stage of growth. A critical stage is from ear initiation through to physiological maturity in grain crops. However, irrigation is an expensive operation and avoidance of water stress at any stage of the development of the crop is of paramount importance if satisfactory returns are to be expected. Where water supplies are limited and have to be rationed, slight deficit stress in crops such as maize and sorghum can be imposed in the young vegetative stage with minimal penalties in yield. The available soil water for plants has been described as that between field capacity and permanent wilting point (Figure 11.10). Field experience has shown the desirability of irrigating the soil before it is completely dry because plants tend to suffer once half the plant available water has been used (Thomas and Moore, 1968; Wiesner, 1970; Meyer and Green, 1980; 1981).

Using the evaporation data (Table 11.15), soil type and available water (Table 11.16) and the root depth of the crop (Table 11.14), it is possible to calculate the irrigation requirements. Allowance must also be made for the efficiency of the irrigation process, defined as the proportion of the irrigation water involved in evapotranspiration (i.e. for crop yield) relative to the amount of irrigation water used. Losses include seepage and evaporation from channels, drains and water storages, uncollected runoff, and percolation below the root zone. Irrigation efficiency may range from 35 to 80 % depending on the quality of management and the irrigation facilities. These issues are reviewed in Finkel (1982).

The following example demonstrates the irrigation schedule for a flowering sunflower crop in January at Griffith, New South Wales (adapted from Dale, 1984).

| | |
|---|---|
| Evaporation from US Class A pan (Table 11.15) | 9.3 mm/day |
| Crop factor | 0.95 |
| Plant available water for soil type (Table 11.16) | 170 mm/m depth |
| Root depth (Table 11.14) | 0.8 m |
| Available water in root zone (170 x 0.8) | 136 mm |
| Available water utilised by crop (say 50%) | 68 mm |

Evapotranspiration = 9.3 x 0.95 = 8.8 mm/day

Days of moisture supply = 68/8.8 = 7.7 days

A crop requirement of 60 to 70 mm would be needed in approximately eight days if rain is not received on the crop during the period. After an allowance for an irrigation efficiency of, say, 70%, an irrigation of 85 to 100 mm would fulfil the requirement at that time

Table 11.14 Effective root zone depths (Doorenbos and Pruitt, 1977) and crop factors (Allen *et al*., 1998) for different crops grown under irrigation

| Crop | Average root zone depth of fully grown crop (m) | Crop factor range [a] (US Class A pan) |
|---|---|---|
| Green Beans | 0.5 - 0.7 | 0.35 - 0.95 |
| Carrots | 0.5 - 1.0 | 0.58 - 0.87 |
| Citrus | 1.2 - 1.5 | 0.58 |
| Cotton | 1.0 - 1.7 | 0.29 - 0.95 |
| Cucumber | 0.7 - 1.2 | 0.41 - 0.83 |
| Lucerne | 1.0 - 2.0 | 0.33 - 0.99 |
| Maize | 1.0 - 1.7 | 0.58 - 0.95 |
| Melons (water) | 1.0 - 1.5 | 0.41 - 0.87 |
| Onions | 0.3 - 0.5 | 0.58 - 0.87 |
| Pasture (grazed) | 0.5 - 1.5 | 0.33 - 0.87 |
| Sorghum | 1.0 - 2.0 | 0.58 - 0.91 |
| Soybeans | 0.6 - 1.3 | 0.41 - 0.95 |
| Sunflower | 0.8 - 1.5 | 0.29 - 0.95 |
| Tomato | 0.7 - 1.5 | 0.50 - 0.95 |
| Vines | 1.0 - 2.0 | 0.25 - 0.58 |
| Wheat | 1.0 - 1.5 | 0.33 - 0.95 |

[a] The crop factor is low early in the growing season and increases with increasing ground cover.

Table 11.15 Mean daily evaporation rates (mm) from US Class A pans (Dale, 1984)

| | Oct | Nov | Dec | Jan | Feb | Mar | April |
|---|---|---|---|---|---|---|---|
| Moree | 6.7 | 9.1 | 10.5 | 9.3 | 8.5 | 7.0 | 5.1 |
| Gunnedah | 6.0 | 7.8 | 9.3 | 8.6 | 7.8 | 6.8 | 5.0 |
| Trangie | 5.5 | 7.4 | 9.5 | 9.5 | 8.2 | 6.4 | 4.6 |
| Condobolin | 5.7 | 8.1 | 10.8 | 10.3 | 9.4 | 6.9 | 4.6 |
| Griffith | 5.8 | 7.9 | 8.9 | 9.3 | 8.6 | 6.4 | 4.1 |

Table 11.16 The average plant available water in different soils types (adapted from Boyle, 1969)

| Soil type | Water available to plants (mm/m depth) |
|---|---|
| Sand | 50 |
| Fine sand | 75 |
| Sandy loam | 110 |
| Fine sandy loam | 144 |
| Loam | 170 |
| Silt loam | 178 |
| Light clay loam | 178 |
| Clay loam | 170 |
| Heavy clay loam | 152 |
| Clay | 144 |

By recording daily rainfall and ascertaining the daily evapotranspiration throughout the growing period, the moisture balance for a given root zone can be calculated on a day-to-day basis. However, summer falls of less than 25 mm are seldom effective and can be largely ignored (Thomas and Moore, 1968).

(e) *Computer water-balance models* These have the potential to provide more reliable and consistent advice than most other methods (Browne, 1984). With computer systems it is possible to adjust the crop factor to account for increased evaporation from wet soils to connect weather stations automatically to the computer, and to provide water-use information quickly for irrigation decision-making on a daily basis.

(f) *Soil water monitoring* There are several water monitoring devices that could be used to measure soil water content or the soil water tension on a regular basis, preferably before and after irrigation application.

(g) *Neutron moisture meter* The use of this device requires a trained operator and involves the installation of access tubes into the root zone following planting of the crop. Soil water levels are monitored regularly during the season by inserting a probe into the access tubes and taking measurements (Figure 11.8). The probe counts the hydrogen atoms in the soil (and hence indirectly measures soil water content changes) by emitting fast neutrons from a radioactive source.

As these neutrons collide with atoms of approximately equal mass, i.e hydrogen atoms, they are slowed down. The slow neutrons are then detected and counted.

The main advantages of the neutron moisture meter are its direct measurement and its ease of operation, recording and interpretation for the trained operator. It provides root-zone water content profiles and can identify compaction layers and water tables. A detailed evaluation of the technique is given in Greacen (1981).

(h) *Capacitance probes and time domain reflectometry* These devices measure the dielectric properties of the soil which is dependent on the water content. Changes in profile water content can be continuously monitored and water applied to match the requirement of the crop.

(i) *Gypsum blocks and tensiometers* These measure how much suction a plant must apply to extract water from soil. Generally, the tensiometers are more reliable when soil water suction is in the range between field capacity and 80 kPa, whereas the gypsum blocks are more suited for drier soil conditions.

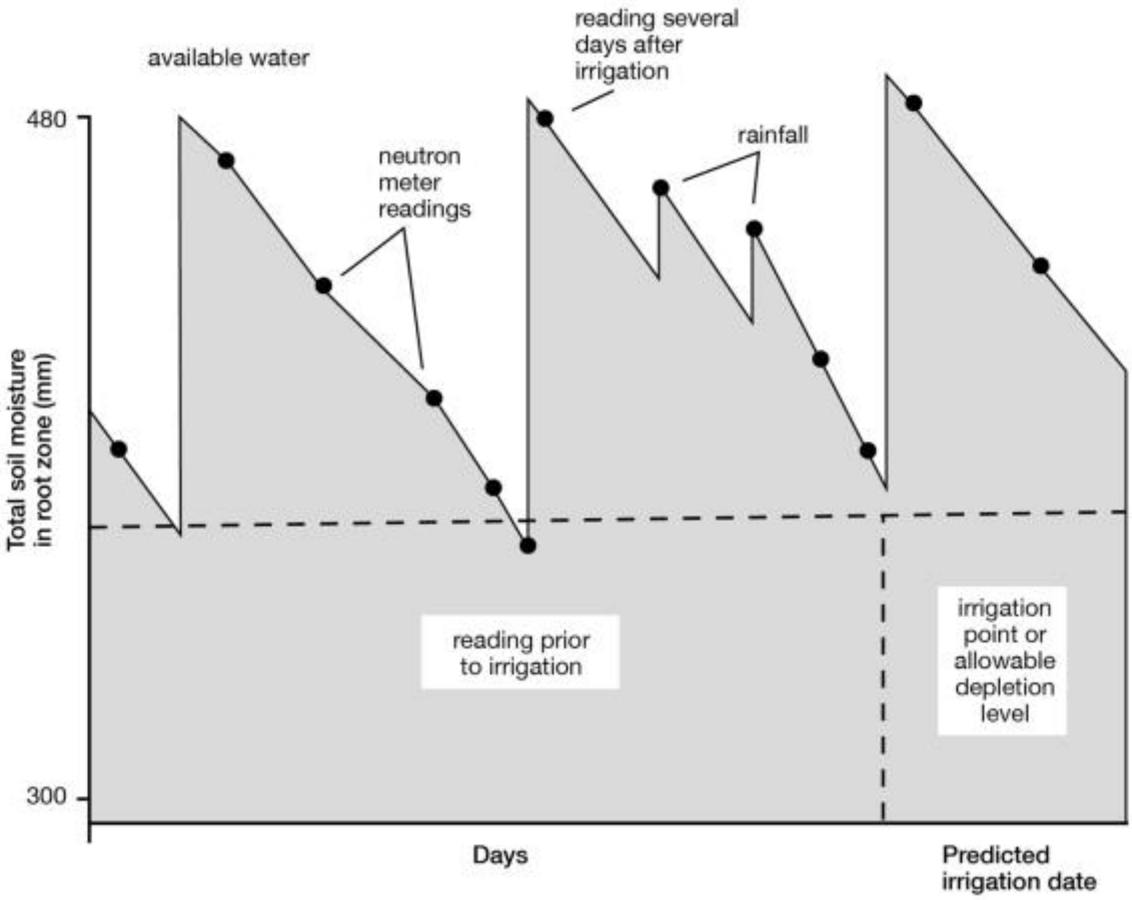


Figure 11.8 Example of soil moisture recorded with a neutron probe. In the absence of intervening rainfall, an irrigation date can be predicted (Browne, 1984).

**Drainage**

Waterlogging occurs when the soil is saturated for a short period of time. It can occur as a result of overwatering, poor soil structure and poor surface and subsoil drainage. Waterlogging reduces crop yields and increases the risks of rising water tables and salinity. The management options include:

(a) *irrigation scheduling* - as waterlogging frequently results from the application of water in amounts greater than required by the crop, scheduling procedures previously outlined match crop requirements with water availability. This reduces water wastage and the risk of waterlogging;

(b) *subsurface drainage* – depending on soil type, a subsurface drainage system will keep the water table at a depth which would help prevent long term waterlogging. If water quality is reasonable the drainage water can be reused, sometimes diluted with high quality water to reduce the level of salinity. Where the salinity of the effluent is so high it cannot be reused, it must be disposed to an evaporation basin where the water is evaporated and the salt harvested for sale (Wood, 1984).

Subsurface drainage is effective only where soil types allow good water movement (Gilbert and Marston, 1986). The costs of installation are high and are usually only feasible for horticultural land. Most of the horticultural land in the Murrumbidgee Irrigation Area is serviced by tile drainage and some by tube wells (Wood, 1984);

(c) *surface drainage* - poor irrigation layout on a paddock or farm basis results in poor surface drainage with temporary waterlogged patches. Whole-farm landforming is therefore imperative to overcome this problem. As surface-irrigated fields frequently lose 10 to 35% of the applied water as tailwater runoff, it is appropriate in any landforming exercise to provide for reuse of the drainage water. The potential benefits from on-farm recycling of drainage water include savings in water charges, improved efficiency of water use, retention of fertilisers on the farm and reduced pollution of rivers and wetlands with nutrients, salts and pesticides. There may be risk of damage to crops from herbicide contamination, depending on the susceptibility of the crop and the persistence of the chemical (Weerts *et al*., 1986).

Regional drainage schemes already exist in many irrigation areas, but to be effective they require well laid out and maintained surface drainage on all irrigation farms (Wood, 1984);

(d) *tree planting* – where appropriate, strategic planting of trees can assist in maintaining water tables at depth by intercepting significant quantities of water which would otherwise add to the water table.

**On Farm Storage**

The construction of large on-farm storages is common, particularly in northern New South Wales and the Darling Downs of Queensland (Barrett, 1985). Although most storages incorporate the tail water return system, their prime purpose is for harvesting unregulated stream flows. Storages provide the advantage of timeliness of application, particularly where there is a lag time for delivery of water. If the ordered water is not required, due to rainfall, it can be stored for subsequent use and is therefore not lost. However, storage of water in small dams can be inefficient due to relatively large losses to evaporation and seepage.

## PRESENT AND FUTURE CHALLENGES: IRRIGATION IN A TIME OF INCREASING DEMAND FOR WATER

The demand for water increased in the last two decades of the 20th Century. In addition to increases in the area of land growing irrigated crops, vines, trees and pastures, the population of Australia reached 19 million people and began to place heavy demands on water supplies. The allocation of water to preserve the ecosystems of rivers was written into water sharing agreements. Industrial demands continued to utilise a portion of the available water. Prices of water traded on the open market indicate the increased demand, especially during periods of low rainfall and when rivers or storage dams have been unable to meet the needs of all users. Water rationing for gardens in cities and towns, which is not uncommon, is also an indicator of how scarce water can be. Now, more than in the past, it is essential to efficiently capture, store, deliver and use water.

The efficiency of delivery of water from dams to the individual irrigation companies or farms is often only about 7%. Losses from supply canals were reported by ANCID (2000) to be due to seepage (4%) and unaccounted losses (17%). Plastic and cement linings of channels and piping water through the worst sections of open canals are being used to improve delivery efficiency. These schemes can be very costly per ML of water saved.

On farms there are also losses in the delivery of water from the main supply to the land which is to be irrigated. Losses to evaporation and seepage, especially in new channels, again account for these inefficiencies. Compaction of the beds of new channels can reduce seepage (Akbar, 2000).

The amount of the delivered water which is actually available to the crops for evapotranspiration also widely varies. In some cases as little as 14% of the water applied to a crop is utilised by the crop.

Irrigators need to constantly reassess water use efficiency and strive to achieve more produce or more income from each unit of water they purchase. Excessive losses to drainage, to wetting soil below the root zone and evaporation need to be identified, measured and eliminated to optimise returns to the producer and to minimise the impact of irrigation on the environment.

**PRINCIPLES**

- Irrigation consumes about 70% of the water used in Australia.
- The area of land under irrigation increased rapidly in the late 20th Century and, together with demands for environmental flows, urban and industrial users, the value of water has become more widely appreciated.
- Irrigation land provides over 30% of agricultural products, worth 50% of gross agricultural production from less than 0.5% of the Australian land mass.
- The uncoupling and trading of water from the land on which it has traditionally been used is increasing the return per ML water used and increasing the labour requirement per ML of water.
- Both the water supply authorities and irrigators are using irrigation efficiency to make comparisons between crops and management practices.
- Water policy is a topic of political significance as Governments balance the need to produce food with the wishes of many in the community to make water available for the environment.
- Improvements in the efficiency of delivery from storage dams to farms and in efficiency of application to trees, vines, crops and pastures requires a sound understanding of soil-water relations, climatic conditions and plant requirements.
- A benefit of furrow and bed irrigation layouts is that only one-fifth to one-half of the total soil surface is flooded, thus reducing evaporation losses and making it possible to cultivate the soil sooner after watering.
- The most significant development in sprinkler irrigation has been the centre-pivot travelling irrigator, which has improved uniformity and efficiency of application and reduced the operating pressures and cost.
- Advantages of drip irrigation include labour and water savings. Irrigation efficiency is high since, if properly managed, there is no run off, little or no deep percolation, minimal evaporation losses, and the inter-row spaces are not watered.
- Two physical forces, *cohesion* and *adhesion*, are responsible for the way water moves through soil in response to gravity.
- Gains in water use efficiency are needed to optimise returns to irrigators and to minimise the impact of irrigation on the environment.

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