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The Irrigation Industry in the Murray and Murrumbidgee Basins

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CRC for Irrigation Futures Technical Report No. 03/05

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Description: Sunset over ancient cliffs on the Murray River, upstream from Renmark, SA. 2002.
File: ASA_RIV001_006.jpg
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Description: Pumping Station on the Murray River at Loxton, SA. 2004.
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Description: Murrumbidgee River with lucerne and wheat crops near Wagga Wagga, NSW. 1999.
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Description: Overhead sprinklers irrigating a vineyard at Loxton, SA. 1989.
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Executive Summary

All Australians benefit from irrigation, either directly through the constant supply of quality fresh fruit and vegetables, grains and fibre or economically from irrigated production that is a significant contributor to national wealth generation. Producing these many and varied food and fibre supplies, and generating wealth with irrigation, requires suitable land, water, capital, infrastructure, skill and institutional organisation. Limits on any of these vital inputs will limit the benefits that can be obtained. Hence concern in Australia, particularly in the southern regions of the continent, about the continuing availability of water has particular interest for irrigators and the industry. However, the ability of the industry to articulate its concerns and to develop a full appreciation of its size, position and importance has been hampered by the lack of a contemporary compilation of the industry.

This study sets out to collate a hitherto scattered set of information on irrigation in the Murray and Murrumbidgee Basins and so provide a "bird's eye view" of irrigation in the south eastern part of Australia. From this "bird's eye view", we present data indicating the size and position of irrigated production and its impact on both the regional resources and the dependent communities. This provides some indicators that illustrate where the opportunities for increased irrigated productivity are located and the conditions that are generally necessary for the opportunities to be realised.

Irrigation – a "bird's eye view"

This study highlights that irrigated production generates a level of economic and community activity that is three to five times higher than would be supported from rain-fed production alone. It also shows that significant opportunity exists for further expansion and intensification of irrigated activity through improved water distribution and application efficiency, and through improved water productivity, largely mediated by improved management skill and controlled irrigation systems.

Economic productivity or profit?

At a National and State level, a major motivator for regional development is the desirability of increasing the economic productivity from the use of resources, often expressed in terms of \$/ha or \$/Ml[1]. While these measures are useful at this broad scale, they do not directly accord with the drivers of activity at the individual irrigated farm enterprise level. This study has illustrated that large returns are almost always accompanied by large capital and skill investment, although this does not necessarily lead directly to high profit - a major and critical determinant of enterprise viability. Irrigated farm businesses that are successful because they are profitable and operated by satisfied people come from the full spectrum of operations, from intense horticulture, annual cropping and dairying. Hence, many profitable irrigated enterprises do not have the same gross return per ha or per Ml. Given the biophysical, market, infrastructure and skill conditions, the current use of resources is profitable and of significant local benefit. Whether, on balance, these resources could be used for alternate purposes with greater net benefit for society as a whole is much less clear.

Although it is useful to have broad scale measures with respect to the use of resources, such measures do not necessarily accord with the drivers at an individual enterprise level. Recognition of this does not diminish the reality that, within similar enterprises, performance is highly variable. Studies of this variability show that it is very strongly associated with variable management capability and that considerable improvement is always possible. Many of these improvements, generally aimed at increasing profit, or increasing ease of

[1] Abbreviation used commonly through this report:

ha = hectare, Ml = megalitre (1 million litres), GL = Gigalitre (1000 million litres), kg = kilogram operation, will bring about improved water and land productivity, often by correlation rather than by causation.

Irrigation efficiency or productivity?

In the discussion above, care has been taken to distinguish the use of terms such as efficiency and productivity. Terminology, or the language used, can assist or confuse communication. In Australia thus far, there has been focus on improved "water use efficiency" as a means of alleviating an increasing "economic shortage of water". While values of Ml/ha and $/Ml are useful measures at a broad scale, they are not efficiency measures. It is appropriate to identify water storage efficiency, water delivery efficiency or water application efficiency i.e. measured water out relative to measured water in. In irrigation, water is used to develop useable or saleable plant product with the aim of optimising water productivity expressed as kg/Ml as a component in maximising enterprise profit. Water, transpired by plants in producing useable material, can be thought of as beneficial depletion; that evaporated from the soil surface is truly lost from the immediate hydrological cycle and is a non-beneficial depletion of water. Land productivity is the traditional measure of yield on a unit area basis i.e. kg/ha.

Irrigated regions in the Murray and Murrumbidgee Basins

The irrigated areas of the Murray and Murrumbidgee Basins were grouped into ten regions on the basis of similarity of regional biophysical conditions, supply systems, commodity production and institutional arrangements. Using data from a range of sources, supplemented by derived productivity and profitability estimates, a comprehensive picture of irrigated activity and its economic and social consequences was developed.

Irrigated area

Within the study regions, the total area irrigated grew by 21% between 1996/97 to 2000/01 to reach 1,243,000 ha. This accounted for 49% of the total irrigated area of Australia. Projections for the 2004/05 irrigation season are for an irrigated area of about 952,000 ha; down from the 2000/01 levels because of restricted allocations from drought affected storages resulting in smaller areas of annual crops (especially rice) and reduced areas of pasture irrigation. Irrigated land within the designated regions account for only 9% of the total area. The capacity of annual cropping to adjust to variable water availability can be viewed as a desirable adaptive response to what will continue to be a variable supply system. While this may not be an ideal financial position at the enterprise level, it does provide resilience in the productive use of the variably available resources. Whether this is the optimum way to manage variability and meet production and environmental management expectations is not clear.

Water for irrigation

Of the 10,960 GL of water diverted for irrigation in the Murray Darling Basin, 8,608 GL (78%) were diverted by the regions in this study. The diversion in Murray and Murrumbidgee was 52% of the estimated runoff and inter-basin transfer recorded in these catchments. Within these regions, 6,656 GL (77%) were recorded as being delivered to farm gates. The Australian water audit of 2000/01 (National Land and Water Resources Audit 2001) estimated a national irrigation water diversion of 16,660 GL showing that the Murray and Murrumbidgee regions account for 52%. Of the water diverted, this study estimates that about 60% of it is applied to various irrigated crops and, of this, about 70% (i.e. 42% of the water diverted) will be beneficially used for transpiration by productive crops. It should be noted that in significant areas of pastures and winter-spring crops, they are not irrigated for maximum productivity but, rather, are opportunistically irrigated to enhance production and provide flexibility for the enterprise mix.

Irrigation delivery and on farm infrastructure

Water for irrigation is commanded and directed through an extensive irrigation channel and drainage system infrastructure that has an estimated replacement value of $3.8 billion. This off-farm investment is complemented by an infrastructure asset value on farm of $6.3 billion together with a total water asset potentially worth more than $6.6 billion. This level of investment is equivalent to the recent annual export value of all Australian agricultural products ($10.05 billion 2001/02, ABS yearbook). In terms of on farm investment, irrigation application methods are continually being upgraded through laser levelling and whole systems redesign of surface irrigation, to centre pivot and lateral move systems of sprinklers and an increasing area of micro irrigation spray and drip. Overall, the ratio of areas irrigated with the different systems is 83 : 10 : 7, surface : sprinkler : micro, respectively. The value of production from these different systems is heavily weighted to the more controlled forms, such that an estimated 40% of the total value comes from the 7% of the irrigated area with horticultural and vegetable production using micro systems.

Irrigated production and revenue

With all this infrastructure, water and expertise, what does irrigation in these regions produce? In aggregate, the regions account for a very significant proportion of all of Australia's fruit, nut and vegetable production. This is best illustrated using the reported value of different commodities. The regions produce 19% of Australia's vegetables, 50% of all fruit and nuts and 63% of all grapes. The combined estimated revenue for these commodities is $1.7 billion or 40% of all fruit, nut and vegetable production (irrigated and rain-fed) in Australia.

With a very significant proportion of all fresh fruit and vegetables coming from these regions, it is not surprising that the revenue generated ($3.1 billion, 2000/01) is a very significant proportion (32%) of all irrigation production in Australia ($9.6 billion) and 9% of the value of all agricultural production. Again, based on the estimated value of all fresh fruit and vegetables traded in Australia, the regions in this study provide one third of these valued commodities to Australian households.

While total revenue is fundamentally important to the economic viability of any activity, the generation of adequate profit is the key determinant of individual enterprises. Reliable profit numbers at enterprise level are difficult to obtain and so estimates derived from known land use areas, generalised farm and commodity costs and returns, and assuming full equity conditions have been used. At the largest aggregated level, the National Land and Water Resources Audit indicated that irrigated agriculture generated 51% of the total agricultural profit for the five year period to 1996/97 from 0.5% of the total agricultural land area. The updated estimate for the Murray-Darling Basin for 2000/01 by Bryan and Marvanek (2004) showed that "irrigated agriculture covered only about 1.4% of the total land area of the MDB, it accounted for around 36% of the total profit generated from agriculture". For the regions in this study, the largest estimated profits for 2000/01, in aggregate, were generated by dairy ($329m), grapes ($289m) and fruit and tree nut crops ($126m). As expected, the largest profits on a per ha and per Ml basis were the intensive horticultural activities; vegetables ($941/Ml), grapes ($651/Ml) and fruit and tree nut crops ($472/Ml).

Irrigated districts relative to rain-fed districts

With the increased productivity and associated activity, what does this do for the regional economic and social situation? To get an impression of this, statistics for adjacent, or near adjacent, but comparable irrigated and rain-fed districts were compared. Aggregating three district pairs, one from each State, shows that the total water input from irrigation above rainfall was 2.4 times greater (4.47 Ml/ha rain-fed, 10.93 Ml/ha rain plus irrigation), with a revenue generation that is 13.1 times greater ($52.45/Ml rain-fed, $686.83/Ml rain plus irrigation). This increased revenue supports a level of economic activity that is three to five times greater than in the adjacent rain-fed district. The population is greater; there are more businesses, more total employment and significantly more services (banks, medical facilities, and recreational facilities) in the irrigated communities. There is some evidence that the intensity of services (number per 1000 people) is greater in irrigated districts. This is most likely a case of service provision in locations of greater population density so that irrigated towns and districts act as service centres for both the irrigation dependent community and the surrounding rain-fed areas. The only significant population centres in areas that receive less than 500mm of annual rainfall are associated with irrigated districts. Tourism is also higher in irrigated districts in total, but the intensity (tourist visits per 1000 population) is not greatly different to rain-fed districts.

Census data on the mix of people in irrigated districts compared with rain fed, clearly shows that irrigated districts have much more diversity in terms of countries of origin and language other than English. The irrigated districts have people from more than twenty five countries while adjacent rain fed districts generally have fewer than ten countries of origin represented. Interestingly, the age distribution in irrigated and rain-fed districts is not greatly different although there is evidence that irrigated districts have a greater proportion (2 to 8% more) of their population under 40 years of age.

Value adding associated with irrigated production

Using generally applicable multipliers associated with the different irrigated activities allowed an estimate of the additional economic activity and employment generated. In aggregate, this activity increased the gross value of the revenue base from $3.1 billion to $4.96 billion (a 60% increase) and employment from 45,000 to 63,000 people (a 40% increase). A significant part of the “upstream” economic activity that supports irrigated commodity production is associated with the irrigation equipment and service sector. Unfortunately, it has not been possible to separate this from other general goods and service provision. When the “value add” activities of processing (dairy, fruit, vegetables and wine) are added as "downstream" activity, then the revenue gross value is doubled and employment is 3.45 times that directly associated with the primary production of milk, fruit, vegetables and wine grapes.

The combination of “upstream” and “downstream” dependent activities associated with dairy, fruit, vegetables and wine grapes has an average economic multiplier of 3.5. This indicates that for every $1000 of farm gate revenue generated, there is an additional $3,500 of dependent economic activity.

Differences between irrigated regions

In looking at the similarities and differences between regions it is quite obvious that there is a substantial difference between those regions in the east, essentially those on the vast Riverine Plain and those in the west within the Murray Basin geological region (i.e. Sunraysia, Riverland and Lower Murray). This difference is best illustrated by the following. NSW Murray region irrigates 321,000 ha with a diversion volume (in a full water allocation year) of more than 2,000 GL to produce irrigated revenue of about $310 million. The Riverland region irrigates 36,000 ha with a diverted volume of 311 GL to produce irrigated revenue of $555 million i.e. one tenth of the area with one sixth of the water producing 1.8 times the revenue – clearly, a more intensive irrigated system. The reasons for this difference can be attributed to fundamental differences of geology, soils, and viability of surface irrigation methods. There are small differences in climate; there are differences in settlement origin and in cultural social mix and in local and state institutional arrangements. In comparing the regions from their origins to their current productivity, it becomes clear that one of the reasons for the success of irrigation in this semi arid, old and tough landscape is the diversity and flexibility of the people and the irrigated enterprises. It would not be very wise to try to reduce the extent of this diversity and flexibility either rapidly or without well informed social and economic intent.

Irrigation and changed river flows

While irrigated production is generally a high intensity activity, and often quite profitable, it is also a large user of resources, especially water. As indicated previously, water diverted by the Murray and Murrumbidgee regions accounted for 79% in 2001/2002 and 81% in 2002/2003 of all the water diverted for irrigation in the Murray Darling Basin. With total diversions for irrigation purposes in the MDB of 10,000 to 11,000 GL per year, and an estimated annual discharge from the Murray of 12,500 GL prior to development, it should be expected that flow and seasonality conditions in the river stem are markedly different. Regulation of the river, through storages, diversion structures and weirs, is primarily directed at providing water for irrigation, for town supplies and to maintain conditions for dependent activities such as tourism and recreation. The heightened awareness of the need to manipulate flow and flood conditions for improved maintenance of in-stream and dependent riverine ecosystems has led to the "Living Murray" proposal being developed through the Murray-Darling Basin Commission. Implementation of this proposal will affect irrigators; its success in achieving a better balance in the beneficial use of water will need the cooperation of irrigators.

Irrigated drainage returns and water quality

While irrigators view the river systems as their primary source of water supply, the rivers remain the drainage lines for the land. They continue to transport large volumes of sediment, organic matter, nutrients, salt and other materials, including chemicals that originate from land use activities. Attributing contributions of salts, nutrients and other materials to irrigated activities, relative to rain fed areas, is not easy. With respect to major nutrient loads in the rivers, survey information has indicated that phosphate discharge was high associated with surface irrigated dairy regions in the Goulburn Broken and Lower Murray regions. Drainage, mainly from subsurface drains in horticultural areas, was generally higher in nitrogen compounds. Concern about nutrient discharges from irrigation will continue because of the connection between low flow conditions, especially in summer, enhanced nutrient levels and the likelihood of toxic blue green algae outbreaks. Increased awareness of the need to limit drainage volumes and discharges to supply rivers has resulted in active management through Land and Water Management Plans and specific nutrient reduction strategies.

The altered river flow regimes indicated above have affected both in-river and riverine ecosystems. The process of installing weirs and diversion structures often drowned nearby wetland and floodplains. The changed flooding regime, indicated by the reduction of small and medium floods from a frequency of eight years in ten, to less than four years in ten has reduced the size and diversity of flood plain vegetation and wetlands in many areas. With the current run of drought conditions, floodplains vegetation health is poor, particularly in the Sunraysia, Riverland and Lower Murray Regions. Although the knowledge base is far from complete, restoring reasonable areas of floodplain and wetland ecosystems is thought to require increased frequency of flooding to connect the floodplain with the river stem followed by controlled periods of drying. The consequence of this need is likely to be greater variability in river flow.

Managing salt from irrigated areas

The difficult dilemma of managing a river, both as a landscape drain and as a water supply system is nowhere better illustrated than in managing salt. Exporting salt from irrigated (and rain-fed) areas and discharging into the river is, in part, mimicking a natural process. However, for people and systems downstream, this can cause unacceptable water quality decline. As the demand for quality water grows, so it becomes more difficult to simultaneously run a drain and supply successfully. Hence, the discharge of irrigated drainage salt loads into the long inland rivers is not an option, at least under low to normal flow conditions. For the Murray, dealing with this dilemma is the focus of the salinity and drainage strategy of the Murray-Darling Basin Commission. The management of salt accumulation and mobilisation associated with irrigation still remains critical. Long term irrigation is not possible if salt, accumulated during transpiration and evaporation of water, is not moved away from the root zone of crops.

Drainage infrastructure, both surface and subsurface, is a large asset of irrigation systems. It is estimated that more than 80% of the total irrigated area in the regions has some form of surface drainage, mostly to manage winter rainfall runoff and surface irrigation tail waters. Subsurface drainage is largely confined to high asset value horticulture and some dairy pasture areas that use shallow aquifer pumping. It is estimated that 200,000 ha, or 17% of the irrigated area, has some form of sub-surface drainage. We believe that this area will increase by at least 20,000 ha involving a capital expenditure of $55million to $75million as greater areas of high value crops are planted. As with any form of drainage, the immediate question is “drain-to-where?” As indicated above, discharging to the rivers is increasingly restricted because of salt loading requirements embodied in the salt credit scheme operating between NSW, Vic and SA. Increasingly, there has been the development of land based salt “disposal” basins that range from individual farm basins to large, community and regional basins. We estimate that in our study regions these have a total area of nearly 14,000 ha, or 1.10% of the area that is irrigated. While every effort is made to hydrologically isolate these basins from the local groundwaters, this is mostly not economically possible. Hence, it is more accurate to think of these basins as salt storage areas, with slow and extended leakage back into the groundwaters.

Irrigation connected to groundwater

The inevitable and direct connection between surface applied irrigation water and groundwater has not always been fully and widely appreciated. Almost all irrigated areas in our study regions have or will develop unconfined aquifers (water tables) that come close (≤ 2m) to the ground surface. For areas around Shepparton (Goulburn Broken), Kerang (Loddon Campaspe) and Wakool (NSW Murray), irrigation has developed on top of “regional” discharging groundwater systems. These systems have become increasingly pressurised as the result of changed vegetation and recharge in the Great Divide catchment to the south.

With irrigation, especially surface flood of pastures and rice, water (and leached salt) has filled the unsaturated soil layers below the irrigated area and on top of the regional rising groundwaters. The result is prolonged wet soil conditions and a predisposition to increasing salinisation, especially since the regional groundwaters are often highly saline. In almost all other areas, irrigation has contributed significant volumes of water (and salt) to the upper layer groundwater system. The well documented rise and spread of the watertable “mound” below the Coleambally Irrigation Area is typical of irrigation development that discounted or ignored the need to manage drainage until evidence of surface effects (waterlogging, salinity, non irrigated vegetation decline, and road and infrastructure damage) became obvious. It is pleasing to note, however, that almost all irrigated areas now have Land and Water Management Plans and/or drainage plans that specifically target drainage rates, and salt and nutrient loadings to groundwaters. More work is needed to characterise the extent and time courses of irrigated drainage connecting with underlying groundwater. This needs to be done in the light of being able to use the subsurface systems as storage for salt and with the caution that once contaminated, cleanup of groundwaters is extremely difficult. There is no doubt that better knowledge of groundwater systems will enable irrigated areas to use them to advantage, through conjunctive use, for short term aquifer storage and recovery and for salt storage.

Irrigated soil condition

Irrigated crop production is an intensive user of the soil. Survey information for the irrigated regions showed a common concern that irrigated soils were subject to a loss of physical structure (compaction), to increasing salinity and sodicity and, in the eastern regions, evidence of increasing acidity. Most of these degrading processes can be managed and recent trends of reduced tillage, increased retention of organic matter, controlled traffic and use of ameliorants such as gypsum are all positive. The knowledge base for the management of soil sodicity and surface compaction is deficient and will become more important, especially as more controlled drip and micro systems are used.

Irrigation, water management, "the Cap" and water trading

Irrigation activity in our study regions is a very significant part of the economic, social and environmental fabric. While highly productive compared with rain fed agriculture, irrigation needs large quantities of water. Some of the major consequences of this water use on the river and riverine ecosystems and on the land and groundwaters of irrigated areas have been highlighted. Heightened environmental awareness and the decreasing dependence of the total Australian economy on agricultural production has brought legislative and regulatory requirements that aim to redress the (im)balance between water extraction, mostly for irrigation, and the judged needs of the river and its dependent ecosystems.

It is against this background, and within a government policy setting of increased competition and greater free market institutional arrangements, that the Council of Australian Government (COAG) and Productivity Commission pronouncements have affected water. Clarification of water ownership, entitlements and allocation has been necessary to assist the development of water trading, now mostly separated from land area.

These changes, together with the foreshadowed increase in allocation of water for the river environment contained in the "Living Murray" proposal (Murray-Darling Basin Commission 2004), will have a profound impact on where and how irrigation is practiced. The imposition of the Murray-Darling Basin "Cap" from 1995 is designed to limit total extraction of water from the rivers to "1993/1994 levels of development". For the Murrumbidgee and Murray systems the annual cap volume is approximately 8,734GL. Audit and compliance processes since 1995 have recorded the increased congruence of the volumes allocated for use, the amounts diverted and the target Cap volume. With water trading, intrastate temporary trade is by far the largest turnover with between 500 and 900 GL being traded annually since 1994/95. Interstate permanent trade, beginning in September 1998 in a limited area on the Murray below Nyah, in Victoria has been quite small (annually, less than 5 GL) with the net result since 1998/99 of 14 GL being traded into the Riverland and Lower Murray regions of SA.

In northern Victoria, the volume of water that has been permanently traded out of the three regions (Upper Murray, Goulburn Broken and Loddon Campaspe) for the period between 1990 and 2003 is 64 GL or 2% of the total annual diversion for these regions. During this time, the average price has ranged from $705/ML in a full allocation year to $1235/ML in the water short 2002/2003 season. There is some evidence that salinity affected areas in the Loddon Campaspe region have permanently traded more water than other regions. Presumably, irrigators realise the increasing asset value of the water entitlement relative to its productive value in salt affected areas. Temporary, within season transfers are much more common and have accounted for 7% of total deliveries in 1995/1996 to 30% in 2002/2003. The large trade in 2002/2003 is associated with the water shortage of that season. Prices for temporary transfer have ranged from $34/ML in 2000/2001 up to $364/ML in 2002/2003.

All the indications are that trade in water entitlements will increase. This will be aided by improved and more consistent definitions and recording of what water related product is being traded and any conditions attached. Thus far, contrary to early regional fears, there is no evidence that the water trade will cause wholesale, permanent loss of water from any one region. The prospect of significant money ($500 million) associated with the Living Murray process being used to fund infrastructure improvement and potentially buy water is likely to influence the water trade, at least in the short term.

Improved water productivity and water savings

There is some evidence that water productivity (commodity produced per unit of water) has improved over time. There are few commodities, apart from rice, that have sufficiently reliable records to assess the change. For rice, water productivity doubled in the period from

1980 to 2000 with water used on an industry basis decreasing from 15ML/ha to 12ML/ha. For dairy in northern Victoria, there is evidence from one property of a doubling in the milk fat produced per ML of irrigation used from 1967 to 1991. For almonds, anecdotal evidence suggests that there has been a 28% increase over the last eighteen years. Again though, the increase is due to increased yield rather than decreased water applied. Theoretical consideration of water productivity suggests that with current genotypes it may only be possible to realise about a 30% improvement above current best practice, mostly by reducing ground surface evaporation and using higher density plantings. We therefore need to look at other parts of the water supply and irrigation system to identify possible areas of significant improvement.

Information, largely developed through the Pratt Water Initiative in the Murrumbidgee Valley, has indicated that significant water savings are possible associated with both the distribution system and the on farm application system. The study highlighted deficiencies in the measurement systems on the river that may account for up to 10 to 15% of the total annual flow. With the irrigation area distribution system, more than 100 GL per year, or about 10% of total delivery, could potentially be saved through greater control, reduced channel seepage and suppression of channel evaporation. Economic assessment indicated that controlling channel seepage to save up to 20 GL/year costs from $400/ML to $2000/ML, depending on the methods used. To realise further water savings, the costs rise by an order of magnitude. For on farm application, analysis of possible change in the MIA indicates that water savings of 60 GL (6% of annual water diversion) would require a capital outlay of $150 million. This outlay is associated with conversion of some existing horticultural crop irrigation systems to drip and some surface irrigated crops to moveable sprinkler systems. Realising water savings through improved application systems is not a linear response, however, since an additional $173 to $377 million would be needed to achieve a further saving of 25 GL.

There is clear evidence from recent experiences in the Sunraysia and Riverland regions that major shifts towards more controlled irrigation systems occurs when there is synergistic investment with delivery system upgrades and on farm application systems. Upgrading delivery from open channel supply to semi pressurised pipelines resulted in an average 40% reduction in the annual delivery volumes. Immediately following the installation of these piped systems there was a major shift in on farm application systems with a trebling of drip installations replacing surface furrow systems. Accompanying the conversion from furrow irrigation to drip systems is evidence that drainage to underlying groundwater was reduced as water table test wells showed increased depths to groundwater.

Irrigators connecting to management of water and land resources

There is a network of agencies and organisations engaged in a wide range of activities that aims to improve the irrigation industry's performance, profitability and accountability. Increasingly, we see a matrix of connections between irrigators, community groups, service industries, state and federal governments, research agencies, educational institutions and catchment groups to develop new and better management practices that also benefit the natural resource environment.

The increasing connections between irrigators and the water and land resources are nowhere better illustrated than in the development of Land and Water Management Plans. Every major irrigated region in the Murrumbidgee and Murray Basins has developed and is implementing some form of natural resource management plan that involves aspects of water, soil and vegetation biodiversity conservation. While the direct connection of the effects of surface and sub surface drainage back into the major rivers is now generally appreciated, there is still considerable contention with respect to the effects of changed flow and seasonality in the Rivers resulting from irrigation water demand. There is also need to bring irrigators e.g. some river pumpers, not currently part of regional Land and Water Management Plans into the fold.

The next step in developing a framework in which the compromises and trades between the overtly productive use of water and the maintenance of resources for multiple uses, including recreational, aesthetic and cultural, has been signalled through the "Living Murray" process. Irrigators can make a substantive case that demonstrates the value of their productivity for their districts, regions and to the nation. They can demonstrate involvement with the necessary processes that are needed to enhance the quality and sustainability of the soil and water resources on which they depend. They will need though to increase their direct involvement with managing the rivers and associated dependent ecosystems to achieve a better balance between productive use and maintenance of the wider values associated with water.

Motivators for change and opportunities for improvement

As indicated above, a primary motivator for water policy reform at both Australian Government and State Government level is to encourage more economic activity from the use of limited water supplies i.e. greater $'s per ML. On the surface this is interpreted as encouragement for production of high value commodities like vegetables and fruit. However at the irrigation enterprise level the major motivator is generation of greater profit, especially if this is accompanied by lower risk from production and market volatility. There is thus a fundamental difference between the motivators of policy and the irrigated enterprise – a difference that needs to be appreciated by policy makers. In the longer term though, there is a happy coincidence between profitable irrigated enterprises, total economic activity, community well being and the need for resource maintenance.

Being clear where irrigator interests lie

For irrigation to prosper in the long term there needs to be continuing access to sufficient water of adequate quality, with low salt content being the primary quality concern. There is thus a coincidence of irrigator and river environment concerns with respect to managing salinity in the rivers. Beyond this, irrigators do not have a primary vested interest in the condition of the river or the dependant riverine ecosystems. Their engagement in the public discussion on the state of the rivers is to ensure that their interest in water supply is maintained through access and allocation policy. The public discussion is largely centred on the perceptions of the net benefits of using water to maintain river and near river ecosystems relative to irrigated production. Apart from tourism and recreational activities the attributes being promoted are aesthetic and cultural – values that can be held equally by irrigators and non irrigators alike. To assure continuity of supply, irrigators need to win the hearts and minds of the voting public so that there is a shared sense of fair and equitable balance of water access and benefit opportunity. To this end irrigators will need to become more involved as managers of the rivers, where management is more than ensuring the supply of water for irrigation. At the water use end there is evidence in land and water management planning that the right of access to water for irrigation is accompanied by conditions of use that enshrine the notions of responsible resource use for everyone's long term benefit.

Significant improvement is possible

There is enough evidence to indicate that every irrigated crop and pasture can improve its median water productivity. The focus should be on improving the productivity of the top third of producers with the expectation of significant improvement in the performance of the middle third. The increasing value and tradability of water will provide opportunity for poor performing producers to realise their asset value and leave the industry. Increased water productivity is clearly of significant benefit to regional communities, especially if this is accompanied by increased diversity of commodity production and associated service industries. The opportunity provided by irrigated production lies in retaining and increasing diversity, flexibility and adaptability i.e. increasing resilience. Increased productivity needs to be stimulated and accompanied by greatly improved water distribution systems. Excessive losses need to be fixed. Small volume, long earthen channels need replacing with pipes and some uneconomic areas need to be retired. Modified systems must be designed to increase flexibility of supply through combinations of greater control, some pressurised with water on demand and with on farm and near farm storage. Conversion of application systems to many crops can free up 30 to 40% of current water use and provide opportunity for expansion or trading for environmental or production uses. The benefits of increased control and measurement in water distribution and application include the capability to target evaporative, seepage, drainage and overflow losses. Control measures can become much more informed and evidence based.

The biggest opportunities lie with the biggest water users

The biggest opportunities lie with the biggest water users, pasture production for dairy and grazing and annual cropping. Dairy water productivity has shown considerable improvement over the last decade, albeit from a very low base. There are good industry examples of greatly improved fodder production systems, from intensive summer fodder to pressurised spray pasture systems. Opportunities for diversity with contracted intensive row crops and trade with rain fed production are all options. Some annual row crop production can benefit from adopting furrow control techniques developed in the cotton industry while on farm storage, both surface and in groundwater can increase flexibility.

There is therefore considerable opportunity for increased production, increased water productivity and a balance between water use for production and that for maintenance of environmental values. Realising the opportunities cannot be achieved through a piecemeal, incremental process, it requires collective action at a regional level so that irrigators, delivery system performance and institutional arrangements work together.

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Introduction

All Australians benefit from irrigation, either directly through the constant supply of quality fresh fruit and vegetables, or economically from irrigated production being a significant contributor to national wealth generation.

We are all irrigators – whether we water our veranda pot plants, lawns, backyard vegetable patch, fruit block, crop or pasture. Very few of us are precise in our water application – witness the pot plants that have withered with excess or insufficient water – did you know how much water your lawn actually needed, let alone the amount that you actually supplied, when you last turned your tap on or set up the automatic timer? Yet we all appreciate that irrigation and the application of water is a vital and pleasing part of our way of life.

But do we appreciate the scale and importance of production irrigation associated with our icon river systems, the Murray and the Murrumbidgee? We probably have a perception that irrigation uses a lot of water from these systems, but how much, what does it produce and how much is it worth? What are the differences in irrigated practice and crops produced by irrigation upstream compared with those downstream along the river? And what do irrigation dependent communities think are the important values that should be better known and appreciated?

This study sets out to collate hitherto scattered information on irrigation in the Murray and Murrumbidgee Basins and so provide a “bird’s eye view” of commercial water use in this part of Australia. From this, some inferences are drawn on the state of the irrigation industry, its distribution and prospects and some of the research and development needs to sustain an important part of our food and fibre production capability and our social fabric.

1 Irrigation in the current Australian context

Irrigation generally requires large volumes of water. Yet in Australia, water diverted for irrigation use accounts for only 4.5% of our estimated total annual runoff. Unfortunately, the distribution of people, suitable agricultural land and water supplies largely don't coincide and this, along with a highly variable rainfall environment, means that most of Australia's irrigation is currently practiced in catchments where water supplies are under increasing demand pressure. In summary, most of Australia's irrigation depends on large volumes of water diverted from supplies that are a small proportion of the total runoff but for which there are increasing demands.

Productivity and profitability from irrigated production is high compared with rain fed agriculture and is, therefore, important in terms of Australia's agricultural production and export value, but in the national accounting of gross domestic product (GDP) it is but a small player (Table 1). And while irrigation generates significant revenue and profit for those involved, it does so by using a large proportion of all the water used (67%) and often in ecologically and environmentally sensitive parts of the land e.g. coastal and riverine floodplains.

Attribute	*Measure*
Total area (ha)	*2,506,000 ha*
Proportion of Australian agricultural area (%)	*<1%*
Proportion of world irrigated area (%)	*1%*
Water diverted (GL)	*16,660GL*
Proportion of total water used (%)	*67%*
Storage volume for irrigation (GL)	*50,500 GL*
Irrigated farm gate revenue ($)	*$9.6 billion*
Proportion of total agricultural production (%)	*28%*
Irrigated farm profit as proportion of total agricultural profit (%)	*51%*
Proportion of GDP (%)	*< 1%*
Export value ($)	*$7.4 billion*
Proportion of total agricultural exports (%)	*25%*
Proportion of total exports (%)	*5%*
Total employee jobs	*171,000*
Proportion of total employment (%)	*2.6%*

Data compiled from: Water Account Australia 2000 – 01 Australian Bureau of Statistics 4610.0 Implications of water reforms for the national economy. Centre for International Economics Final Report July 2004. Prepared for the National Program for Sustainable Irrigation

Table 1 – Attributes of Australian irrigation

Irrigation is practiced in all agro-ecological regions of Australia – from the winter dry tropical regions of northern Australia to the temperate summer dry regions of central and northern Tasmania (Figure 1). Most irrigation is in the south eastern part of the continent with 72% of all irrigated area in the Murray Darling Basin. The diversity of environments in which irrigation is practiced is probably wider than for any other country in the world and allows Australia to produce a great variety of irrigated products and also to provide irrigation expertise to other comparable irrigated areas of the world.

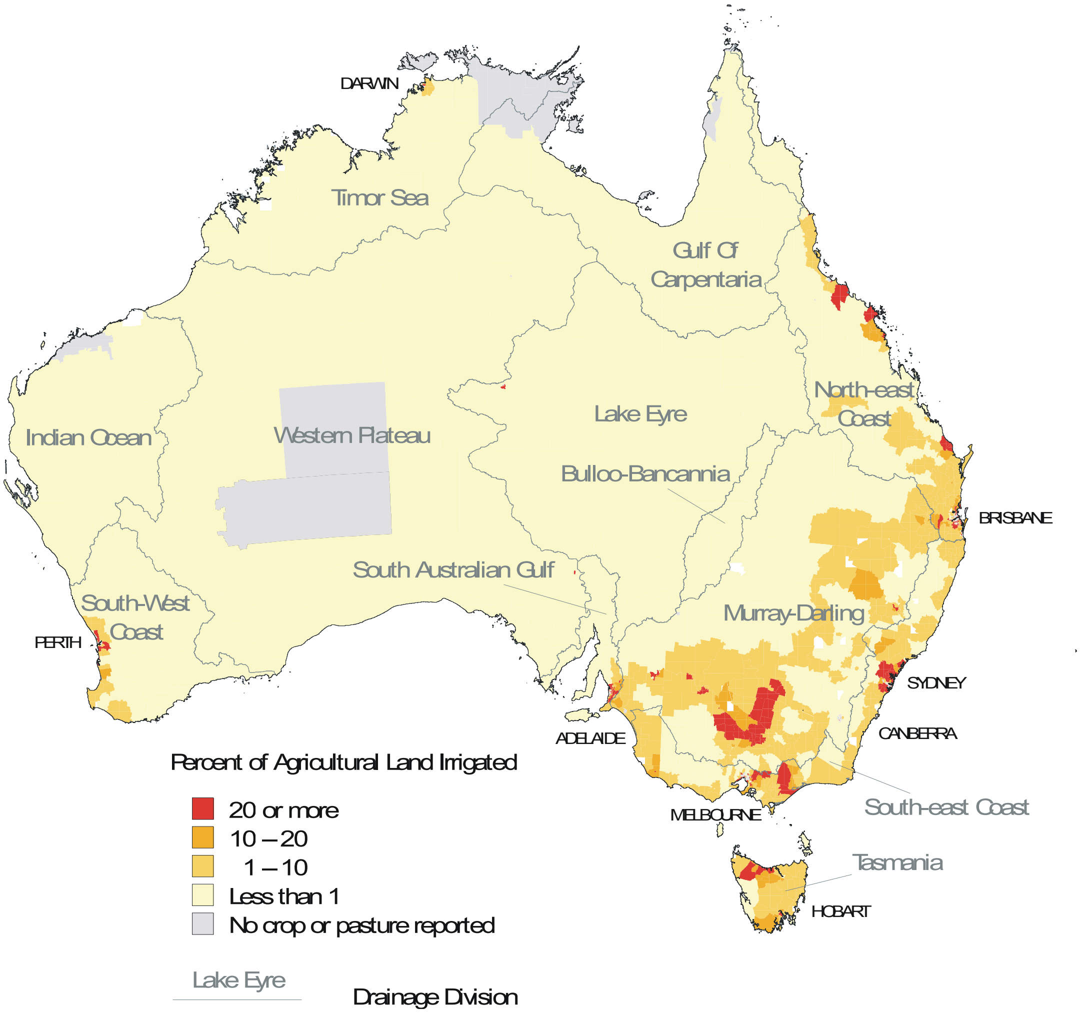

Figure 1 – Irrigated areas of Australia shown with respect to the major drainage divisions.

(Figure with permission from Australian Bureau of Statistics 2004).

2 Brief history of Australian irrigation development

2.1 Timing, motivation and the Murray

Water has massively shaped Australia's coast and landscape features, it has determined where and when people move across the land, where they have settled and, ultimately, determines the abundance and richness of our food and fibre production.

Making use of the available water resources triggered the imagination of many early settlers. The large irrigation areas of south-east Australia were developed with public investment in dams and delivery infrastructure as part of nation building. Subsequently, came the soldier settlement schemes – deliberate and considered social engineering schemes. Many of them have been resounding successes in a social and community sense, although some have argued (Davidson, 1969) that they have not been a sound economic investment and that alternate infrastructure would have delivered greater economic returns – a hypothetical and untestable assertion.

Australians take odd pleasure in proclaiming that we live on the driest inhabited continent, yet our water use footprint, whether in an urban or rural setting, is larger than almost all other industrialised countries. We try to assure ourselves that we are using this finite and seasonally variable resource to best advantage as we become more conscious of its value, potential productivity and the need for conservation. This attitude change is driven by the connected forces of geographic and environmental awareness, economic pressures and increasing understanding of the eco-system in which we live. Our society is becoming more receptive to the arguments for responsible water management as we move from "pioneering exploiter to long term custodian".

The Murray flows for 2530 km through three states, rising in the Australian Alps, 40 km south of Mt Kosciusko at an altitude of 1430 m. The Murrumbidgee rises not far to the north of the Murray and they join forces just upstream from Boundary Bend. Measured against other major world rivers, the Murray's flow is 16% of that of the Nile, less than 3.5% of the Mississippi and 0.25% of the Amazon. The Amazon discharges the Murray's annual flow in less than one day. Apart from the relatively limited water associated with the Murray system compared to other major rivers of the world, the variability of water runoff into the river is also much greater than other comparable world supplies (McMahon et al. 1992). This is one reason why the volume of storage in the Murray Darling Basin (2.8 times annual use) is higher than the world average (1.7 times annual use).

Near its beginning the Murrumbidgee supplies Canberra and the ACT with domestic water.

Towards the end of its journey, the Murray must supply a large part of South Australia with water for domestic and industrial use. In an average year, half of Adelaide's water comes from the Murray and it is also piped to Yorke Peninsula, Port Pirie, Whyalla and Port Augusta and the south east of South Australia ("The Murray", Murray-Darling Basin Commission, 1990).

2.2 Early irrigation development

The earliest irrigation developments in Australia were undertaken in the coastal settlements of New South Wales (around Sydney) and in Tasmania (see Blackburn, 2004 for a comprehensive account). In the mid 1800s, pastoral development (primarily grazing of sheep) began on large flat inland tracts of south-central and south-western New South Wales and northern Victoria. Grazing sheep for wool was jeopardised by the frequency of drought, making access to waters of the inland rivers critical for the survival of these settlements.

Agitation for insurance against the effects of drought through irrigation was in part responsible for the formation of the Deakin royal commission of Victoria in 1884. Deakin visited the USA, India and other irrigation areas and strongly recommended the development of large irrigation schemes in Victoria. He was impressed by irrigation in California, a semi-arid climate quite similar to that of northern Victoria. The USA influence was also important in directing the control of water away from the problematic "laissez-faire" system of governance of water in western USA towards state government control of water resources. This resulted in the Victorian Irrigation Act of 1886 which ensured all water rights rested with the government and, to a large extent, committed it to carry out major water storage and regulation works. Similar laws followed in other states.

Early attempts at forming private Irrigation Trusts were largely unsuccessful, returns from water sales were inadequate and returns from irrigated production were generally poor. As early as 1885, the engineer Gordon, urged caution in assessing the costs and benefits of large irrigation schemes. However, his protestations were largely ignored as was his advice about the need for irrigation to be accompanied by adequate drainage.

The scene was set for irrigation to proceed, largely with Government control and backing and with a focus on support for the pastoral industry. At the instigation of the State Governments of South Australia and Victoria, the Chaffey Brothers' developments at Renmark and Mildura proceeded with optimistic enthusiasm. Within a decade, however, they both moved from grand vision to difficult implementation to essential failure caused by such fundamental problems as the cost of lifting water from the river, seepage losses from unlined channels, poorly adapted crops, lack of land transport and poor farming skills. But persistence prevailed and both areas are now productive irrigated regions, largely due to the determination of individuals to overcome problems and Government willingness to inject capital into infrastructure, research and extension (see Mack, 2003 for an account of South Australian developments).

These early developments set the framework for the irrigation industry in Australia. With few exceptions, most irrigation development has been motivated and supported by social and political ambitions. Identifying and implementing biophysical production systems that will sustain the irrigated practice in a variable commodity market over time still remains a major challenge for the irrigation industry and the Nation.

2.3 Irrigation in the Murray and Murrumbidgee Basins

The area of study is indicated in Figure 2 with the regions associated with the (two main) river systems aggregated into ten agri-ecological zones. The basis for these zones is an arbitrary aggregation of regions with similar practices and approximate commonality of institutional arrangements, such as water distribution authorities. These zones have quite close correspondence to irrigated catchment areas generally recognised in Murray Darling Basin Commission documents. The coincidence of the regions with the detailed map of irrigated land use is shown in Figure 4 in Section 3.1.

Appendix 1 contains information about the development of irrigation in the following areas:

- Upper Murrumbidgee River
- Murrumbidgee Irrigation Area (MIA)
- Coleambally Irrigation Area (CIA)
- Murray Valley of NSW
- Northern Victoria
- Sunraysia, Riverland and SA Lower Murray

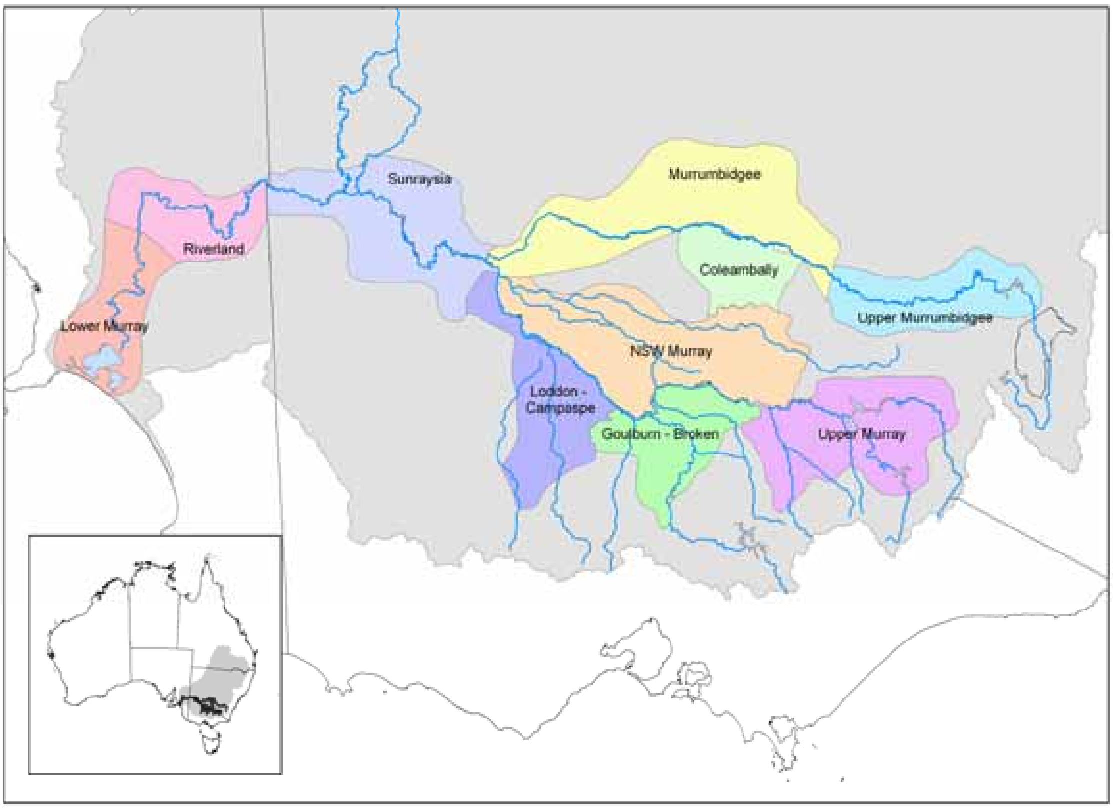

Figure 2 – Location of the ten irrigated regions associated with the Murray and Murrumbidgee Basins of the southern Murray Darling Basin.

2.4 Current irrigation – a reflection of conditions and history

The irrigation practice we see today is determined by fundamental and underlying biophysical conditions, the climate, soils, topography and the social, political, financial and institutional structures and influences imposed. From its beginnings, irrigation has been the product of a trial and error selection process, at times an imposition of human will which may or may not have an enduring effect.

The “bird’s eye view” of irrigation across the Murray and Murrumbidgee Basins highlights the striking difference in practice between the “upstream” Riverine areas and the “downstream” Mallee areas. The Riverine areas were developed to support pastoral grazing activities. The large, flat riverine plains made irrigation with gravity systems easy to construct while the often heavy clay soils enabled surface irrigation of pastures and broad-acre crops. Horticultural activity was initially confined to selected areas of more freely draining soils.

In contrast, the downstream Mallee areas required water to be lifted from the river “trench” and applied to much lighter textured calcareous sands over various depth clay layers. Growing broad-acre crops was uneconomical due to the expense of pumping water and limited flows – hence more emphasis was placed on growing small areas of horticultural crops, initially with furrow irrigation but quite quickly with fixed sprinkler systems and, more recently, with micro systems.

A common characteristic across both the Murray and Murrumbidgee regions is that soils are old and well differentiated and, while some have direct marine origin, they all have high levels of rain-carried sodium salts. With the predominantly alluvial origins of the upper sediments across the basin, there is an extensive and complex arrangement of groundwater aquifers. In the eastern riverine regions of northern Victoria and southern NSW the aquifer systems are often regional and extensive and changes in the aquifer recharge areas are often expressed in discharge areas many kilometres away (see Figure 11, section 3.8.1).

This is the case for the Kerang and Wakool regions where irrigation areas were developed on top of discharging regional groundwater. If this strong groundwater influence had been fully understood and appreciated by the political influencers at the time it is unlikely that irrigation development would have proceeded. Similarly, in parts of western Victoria and South Australia, irrigation development on top of highly saline groundwater with quite short transmission times to the River Murray would not have been advisable. With the benefit of greatly improved information and hindsight more care might have been taken in selection of areas suitable for irrigation and the development of irrigated crop systems better attuned to the resource base and its limitations.

Figure 3 - Ibis rookery at Kerang

The lesson to be learned from this is that we must continue to adapt and modify as our knowledge base improves and to better define the minimum requirements to obtain best value for the water we use and ensure irrigation system longevity.

3 Current irrigation within the study regions

3.1 Areas irrigated

The total irrigated area for the ten regions is nearly 1.3 million ha. This accounts for 50% of all irrigated area in Australia. Figure 4 shows the distributed irrigated land use and Figure 5 indicates the area distribution among the regions. The area associated with the western Murray basin region (Lower Murray, Riverland and Sunraysia) accounts for 8% of the total. Clearly, the bulk of the irrigated practice is located in the "riverine" portions of the eastern Murray Basin and the Murrumbidgee Basin.

In the four year period from 1997 to 2001, the total area of irrigation in the study region increased by more than 200,000 ha or 21% (see Table 2).

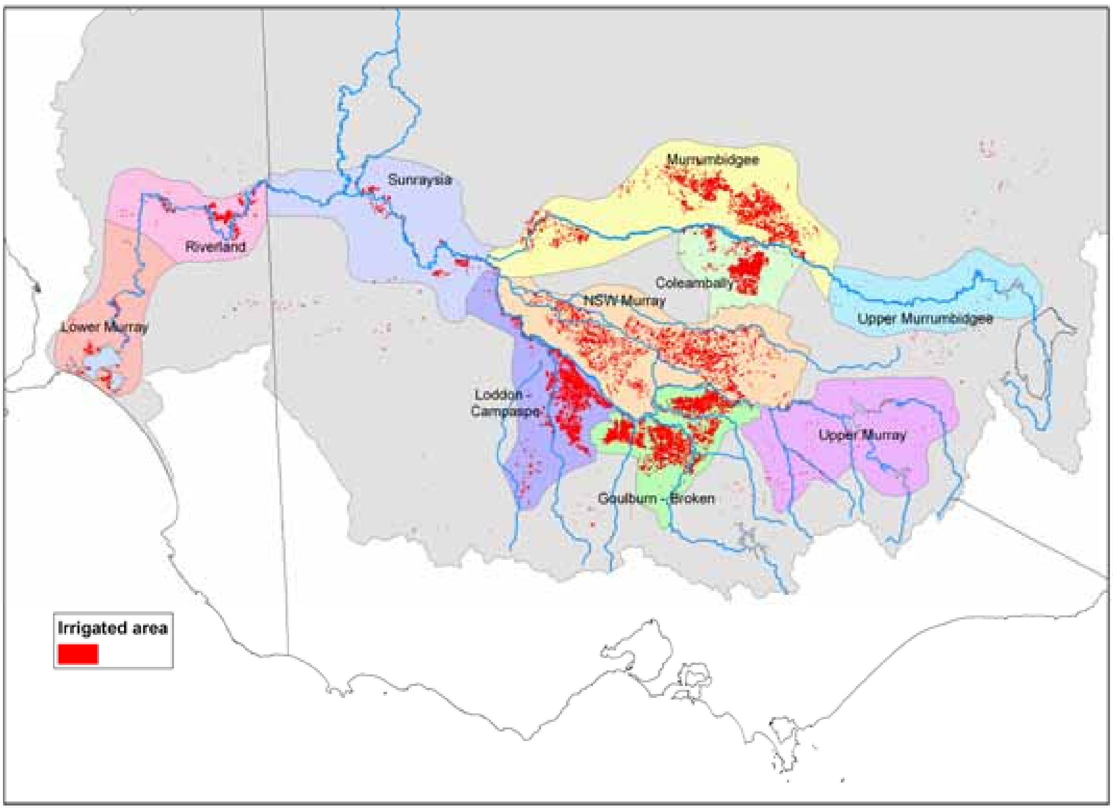

Figure 4– Distribution of all irrigated land area (2000/2001) in the Murray and Murrumbidgee Basins.

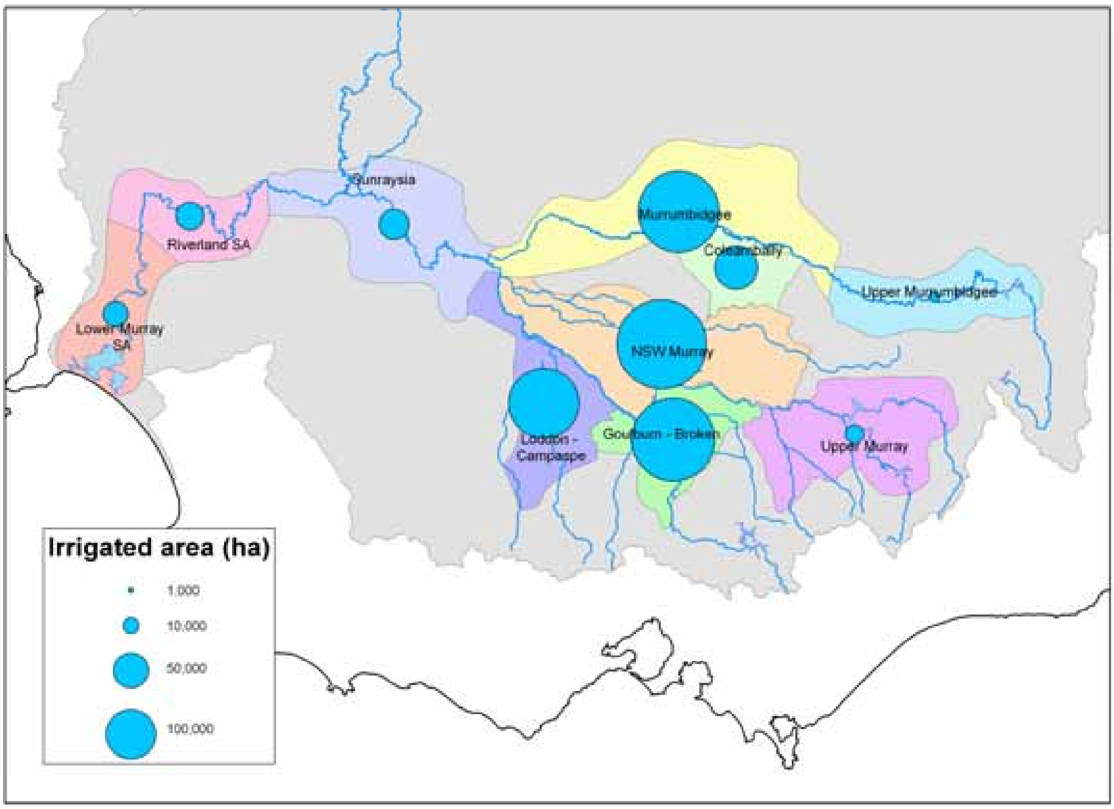

Figure 5 – Indication of the area that is irrigated through the regions.

3.2 Main crops

Table 2 provides details of land use/crops in the regions while Figure 6 graphically illustrates the difference among regions. In the western regions, fruit and grapes dominate; in Victoria, south of the Murray, dairying is clearly the biggest activity, while in NSW, rice and dairy pastures are predominant. Comparisons between 1997 and 2001 data show that the major increases in irrigated crop areas were cereals and dairy pasture, while grapes, fruit (including nuts), vegetables and cotton (in the Murrumbidgee) all increased. There was a significant decrease in pastures used for beef and sheep grazing.

Projections of the irrigated land use for 2004/05 are shown in Figure 7. The projections are based on trends apparent in the 1996/97 to 2000/01 period for continued growth in high return crops such as grapes, vegetables, fruit and nuts. There is expected to be a continued decrease in sheep and beef cattle, while the rice area is expected to be about 1/3 of that in 2000/2001. There is little doubt that the reduction in available water during the extended dry period from 2001/2002 will have a significant impact on total revenue, particularly from the pasture related enterprises and rice.

The estimated total irrigated area for the ten regions is:

1996/97 1,024,000 ha; 2000/01 1,243,000 ha; 2004/05 952,000 ha.

A comparison of the estimated value of all the fruit and vegetables produced in the regions with the estimated total value of all Australia's fruit and vegetables shows (Table 3) that they account for nearly one third of the total. If grapes are included in the fruit category then the proportion increases to 40% of Australia's total. The total grape production in the regions is 63% of all Australian production.

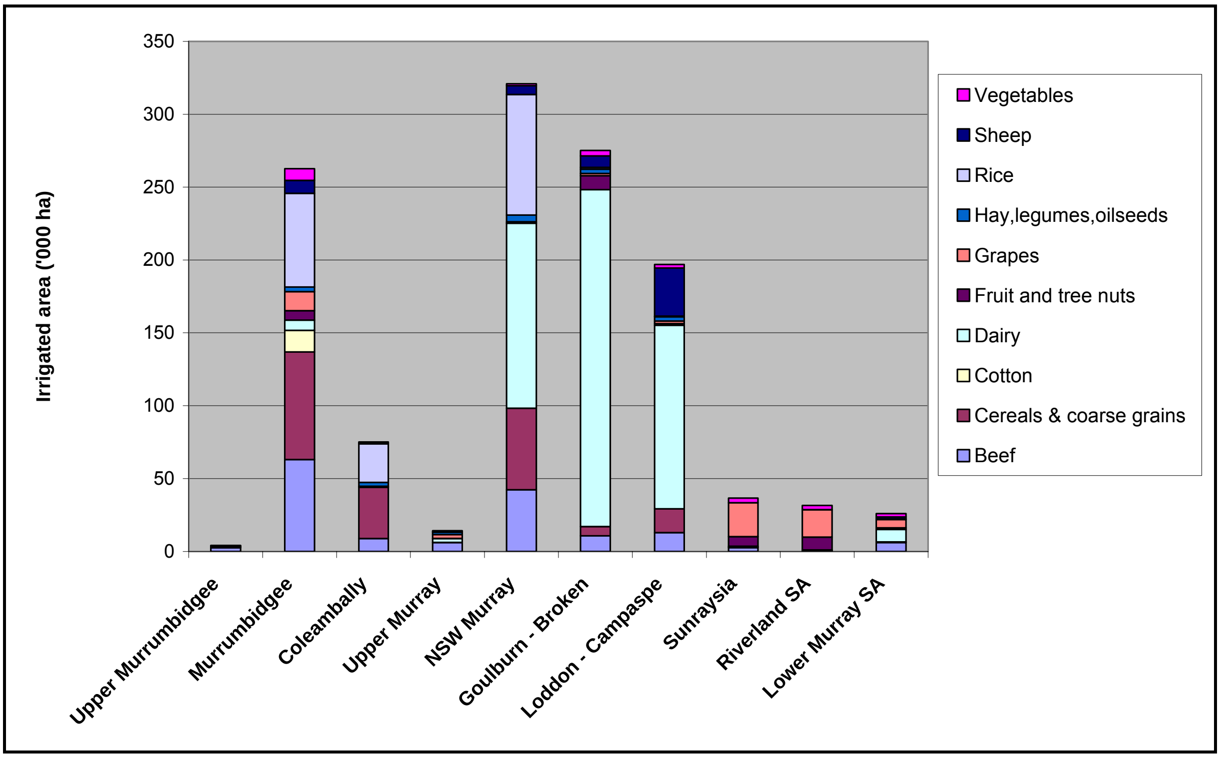

Figure 6 – Regional distribution of different irrigated land uses.

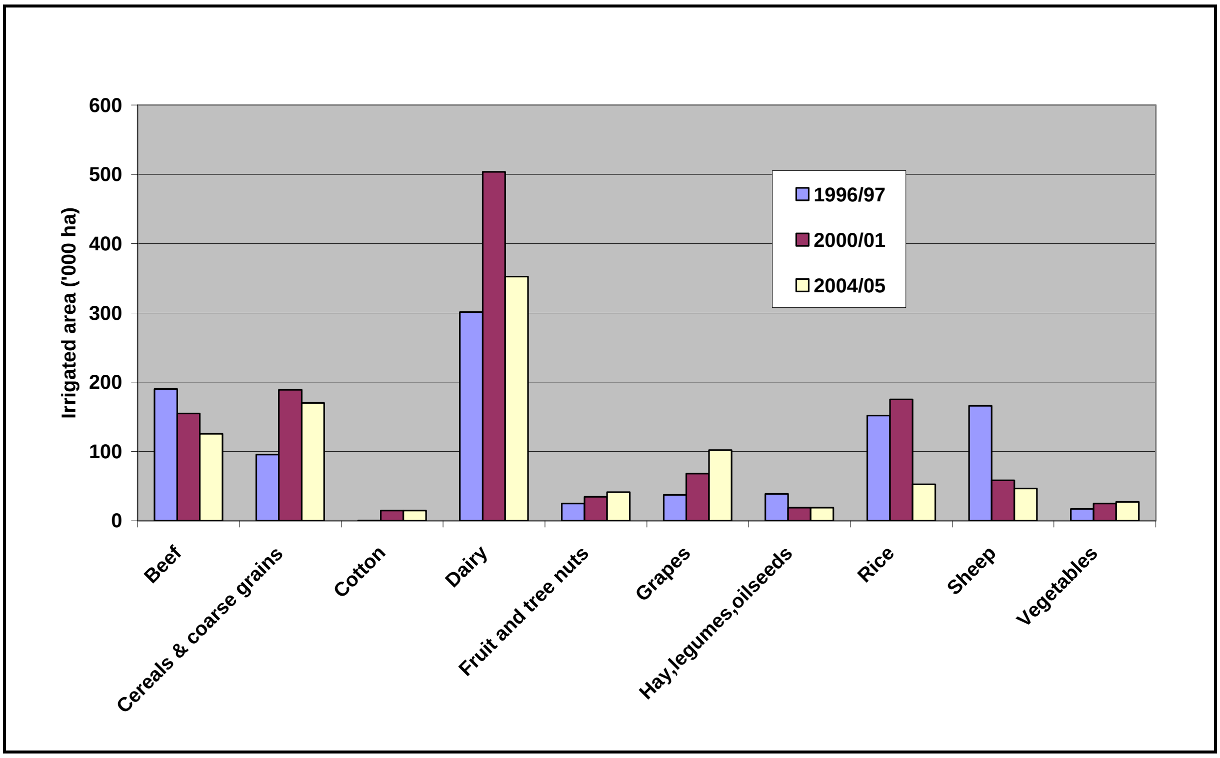

Figure 7 – Estimated distribution of different irrigated land uses for 1996/97 and 2000/01 together with a projected estimate for 2004/05 based on existing trends and effect of restricted water availability.

Irrigated land use (areas in ha)	Data	Upper Murrumbidgee	Murrumbidgee	Coleambally	Upper Murray	NSW Murray	Goulburn - Broken	Loddon - Campaspe	Sunraysia	Riverland SA	Lower Murray SA	All Regions
Beef	1996/97	1,708	53,814	8,456	3,030	79,914	20,465	20,004	659	424	1,402	189,876
	2000/01	2,546	63,078	8,803	6,087	42,301	10,692	12,924	2,631	309	6,101	155,473
	% Change	49.0	17.2	4.1	100.9	-47.1	-47.8	-35.4	299.5	-27.1	335.3	-18.1
Cereals & coarse grains	1996/97		55,436	12,743		12,379	3,472	10,888	396		91	95,404
	2000/01	160	73,855	35,063	147	55,914	6,455	16,341	414	78	485	188,911
	% Change		33.2	175.1		351.7	85.9	50.1	4.5		433.2	98.0
Cotton	1996/97		266									266
	2000/01		14,776									14,776
	% Change		5,454.7									5,454.7
Dairy	1996/97		405			27,306	174,733	89,914		826	7,991	301,176
	2000/01	444	7,006	322	2,609	127,015	231,056	125,965	465	727	8,468	504,075
	% Change		1,628.8			365.2	32.2	40.1		-12.0	6.0	67.4
Fruit and tree nuts	1996/97	247	5,100		132	82	6,758	47	4,883	7,387	413	25,049
	2000/01	160	6,444	421	165	150	9,639	1,109	6,676	8,673	1,077	34,515
	% Change	-35.1	26.4		25.0	83.9	42.6	2,260.5	36.7	17.4	160.9	37.80
Grapes	1996/97	130	7,357	124	888		635	1,125	14,859	11,252	1,942	38,313
	2000/01	356	13,004	148	2,514	761	1,554	1,695	23,251	18,767	5,813	67,864
	% Change	173.8	76.8	19.0	183.2		144.6	50.6	56.5	66.8	199.3	77.1
Hay, legumes, oilseeds	1996/97		13,889	5,935	1,039	11,269	3,403	2,620	92	277	709	39,232
	2000/01	163	3,312	2,605	1,699	4,720	2,922	3,096	27	173	410	19,126
	% Change	173.8	-76.2	-56.1	63.6	-58.1	-14.1	18.2	56.5	-37.4	-42.2	-51.2
Rice	1996/97	120	54,315	27,271	409	69,113	640					151,868
	2000/01		64,332	26,380	202	82,729	1,259	395				175,297
	% Change	-100.0	18.4	-3.3	-50.6	19.7	96.7					15.4
Sheep	1996/97	845	39,659	2,605	5,025	60,685	10,868	43,602	847	345	1,639	166,122
	2000/01		8,786	562	800	5,916	7,877	32,950			1,315	58,206
	% Change	-100.0	-77.8	-78.4	-84.1	-90.3	-27.5	-24.4	-100.0	-100.0	-19.8	-65.0

Vegetables	1996/97	532	5,141	1,197	109	1,502	2,089	1,006	2,545	1,309	1,623	17,053
	2000/01	200	8,029	854		1,379	3,661	2,453	3,156	2,779	2,274	24,787
	% Change	-62.4	56.2	-28.6	-100.0	-8.1	75.3	143.8	24.0	112.3	40.1	45.4
All Land uses	1996/97	3,582	235,382	58,331	10,362	262,249	223,065	169,207	24,281	21,820	15,810	1,024,359
	2000/01	4,029	262,623	75,156	14,224	320,886	275,114	196,928	36,621	31,506	25,943	1,243,031
	% Change	12.5	11.6	28.8	33.8	22.4	23.3	16.4	50.8	44.4	64.1	21.3

Table 2 - Estimated areas of different irrigated land uses by region including the estimated change between 1996/1997 and 2000/2001.

	Upper Murrumbidgee	Murrumbidgee	Coleambally	Upper Murray	NSW Murray	Goulburn - Broken	Loddon - Campaspe	Sunraysia	Riverland SA	Lower Murray SA	All Regions
% of Aust. total fruit & veg.(incl. grapes)	0.1	6.1	0.3	0.4	0.6	6.5	1.2	10.2	12.5	2.8	40.7
% of Aust. total fruit & veg.(excl. grapes)	0.1	5.5	0.4	0.1	0.7	9.7	1.1	4.7	7.1	1.6	31.0

Table 3 – Proportion (% by revenue value 2000/2001) of the total Australian fruit and vegetables produced in each region with and without grapes included.

3.3 Total water used

Aggregating values of water associated with irrigation is a challenge. It is difficult to find consistently reported data from the various agencies, companies and departments for a particular year.

Table 4 collates water volume measures associated with irrigation. Ideally, we would like to have aggregated values for the different components in the water supply system ie:

- volume of irrigation entitlements,
- volume diverted from surface and groundwater supplies,
- volume that is delivered to the irrigated paddock, and
- volume that is used directly for crop production.

The need for more consistent and comprehensive measurement of water supply, entitlement, diversion, application and use becomes obvious when decisions about increasing the value derived from water are being contemplated.

The total water accounted as that diverted from the Murray and Murrumbidgee River systems in 2000/2001 was 8608 GL. Data from the MDBC web site (www.mdbc.gov.au/publications/factsheets/water_resourcesver2) lists the use of average available water (runoff and inter-basin transfers) in each river valley. From this total runoff to the Murray and Murrumbidgee is 15,271 GL with an inter-basin transfer of 1,118 GL giving an available total of 16,389 GL. Using this average, the irrigation diversion in 2000/2001 is 52% of the total.

The data in Table 4 show that in 2001/02 when storage volumes were quite high, bulk diversions were at or above the aggregate of water entitlements. However, in 2002/03, allocations were reduced and this significantly reduced diversions, a situation that has continued for the following two years. To illustrate the variation between years the total delivery volumes for Murray Irrigation Limited have been:

1999/2000	675 GL
2000/2001	1,295 GL
2001/2002	1,239 GL
2002/2003	339 GL
2003/2004	658 GL

These delivery numbers are representative of the water availability situation in the NSW and Victorian regions over the last five years and show that the two seasons, 2000/2001 and 2001/2002 primarily used in the aggregation of information for this study were quite similar. These seasons are also representative of full water availability years. Given the changes in water allocation rules associated with water sharing plans in NSW it is probable that there will be slightly less water available for irrigation allocation beyond the current drought situation. It is not yet clear what the full extent of this change will be.

Anecdotal evidence suggests that the reduced availability of surface water, particularly in the Murray regions of NSW and Victoria, has resulted in an increase in groundwater use. It has not yet been possible to aggregate the estimates of this increase because complete regional estimates are unavailable. The amount of total water delivered and, therefore, recorded at the farm gate, is variably reported. In regions where the numbers were not available, estimates of farm gate delivery were made by adjusting the diversion volume by the reported delivery system efficiency (ANCID 2004a, b). Delivery system efficiency figures are the self-reported values collated in the ANCID System Benchmarking report. We suspect that these efficiencies represent the high end of delivery system performance because data reported by Murray Irrigation Limited and Coleambally Irrigation Cooperative Limited, in their 2002/2003

Annual Reports, indicate that in a season of very low total water delivery the efficiency values were 55% and 61%, respectively.

Bearing in mind that the “cap” on water diversions from the rivers of the Murray Darling Basin was implemented in 1995, it is initially surprising to see that the area of irrigation increased by more than 200,000 ha between 1997 and 2001. At first glance, this would indicate that more water would be needed - but, given the audited compliance with the “cap”, it suggests that water for irrigation is being used much more effectively than previously. Anecdotal accounts, supported by reports from the irrigation water distribution companies and agencies, suggest that management of distribution through tighter control of channel overflows and fixing some losses has improved system delivery efficiency. We also speculate that the effectiveness of irrigation at farm level has increased through a combination of improved irrigation practice and better controlled water application systems. There is also anecdotal evidence of increased groundwater use for irrigation.

There is certainly evidence that irrigation water is valued more – borne out by the increasing price being paid for permanent water entitlement transfers (see section 6.3).

Aggregating the ideal crop water requirement for maximum productivity on a crop by crop basis shows that, in theory, the total exceeds the total water entitlement, is close to the total water diversion and exceeds the farm gate delivery value by 25%. The reason for this discrepancy is that a substantial area, particularly irrigated pasture, is not irrigated to the maximum productivity level i.e. many pastures and some crops are not “fully” irrigated.

Region	Irrigation water entitlement (GL)	Surface water diversion 01/02 (GL)	Surface water diversion 02/03 (GL)*	Ground water diversion 01/02 (GL)	Assumed delivery efficiency (%)	Irrigation water delivery at farm gate 01/02 (GL)	Estimated irrigation water requirement 01/02 (GL)	Estimated irrigation water use 01/02 (GL)
Upper Murrumbidgee (upstream of Narrandera)	40	39	45	37	85	33	19	
Murrumbidgee (MIA, Districts and Lower Bidgee)	1,748	1,638	1,248	83	78	1,277	1,532	
Coleambally (includes Kerarbury Channel and outfall district)	629	662	492	101	80	529	447	
Upper Murray (including King, Kiewa, Ovens, Mitta Mitta)	25	21	33	28	85	18	53	
NSW Murray (Murray Irrigation Limited, west Corurgan)	1,954	2,092	879	256	76	1,590	2,271	2,456
Goulburn Broken (including Yarrawonga canal)	1,619	2,167	1,515	45	75	1,625	2,031	
Loddon Campaspe (including National Kow Swamp channel)	790	1,029	828	16	75	771	1,417	
Sunraysia (SwanHill to SA border)	362	467	478	6	80	374	213	253
Riverland SA	349	311	336	5	95	295	247	275
Lower Murray SA (including Swamps and Lake supply)	218	183	196	25	78	143	137	
	7,734	8,608	6,049	602		6,656	8,367	

*Note: For comparison, the surface water diversion for 2002/2003 is included to show the effects of reduced storage and allocation under drought conditions

Table 4 – Water entitlements, diversions and estimated requirements by region for 2001/2002.

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3.4 Irrigation infrastructure

Assessing the value of the assets (control structures and channels) associated with distributing water is complex because of the different accounting and reporting approaches taken by different companies and state agencies. We settled on assigning a replacement valuation for the delivery systems assuming that they would be the same as currently exists. For on farm assets we confined our valuation to the current estimated establishment costs for water application. This includes the cost of land forming, irrigation system design, installation of control structures, pumps, pipes and field drainage systems and the costs of tree and vine (with trellis) establishment. The establishment costs of horticultural crops, for example, will differ depending on the irrigation system employed.

Figure 8 shows the distribution across regions of supply and drainage channels and pipes. The total valuation of these is $3.77 billion (see Table 16). This compares with an on farm valuation of $6.33 billion, a ratio of 1:1.8 implying an on farm investment that is, in aggregate, twice that of the supplying distribution infrastructure. By any measure this is a very large asset. The distribution across regions of the on farm assets is shown in Figure 9. If the asset value of water valued at $1000 per ML is added to the farm valuation this would account for nearly $7 billion.

Assessment of the revenue returns by land use and region is considered in section 4.

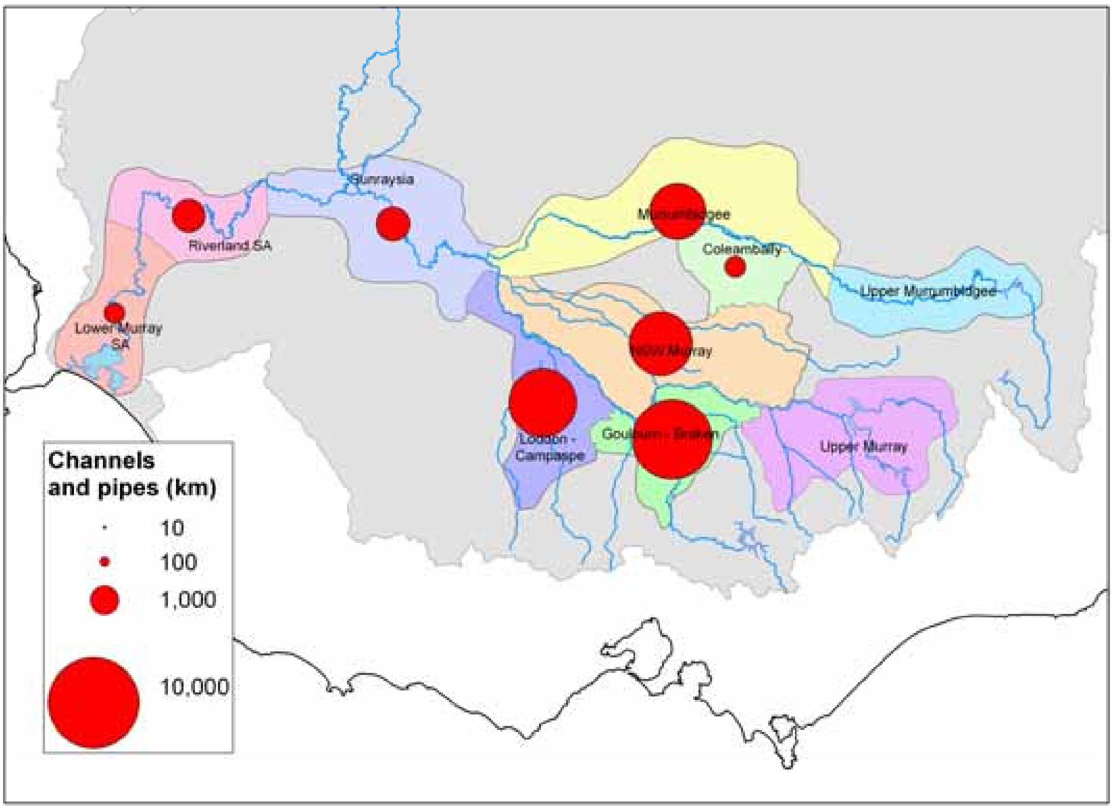


Figure 8 – Distribution across regions of the lengths of supply and drainage channels and pipes.

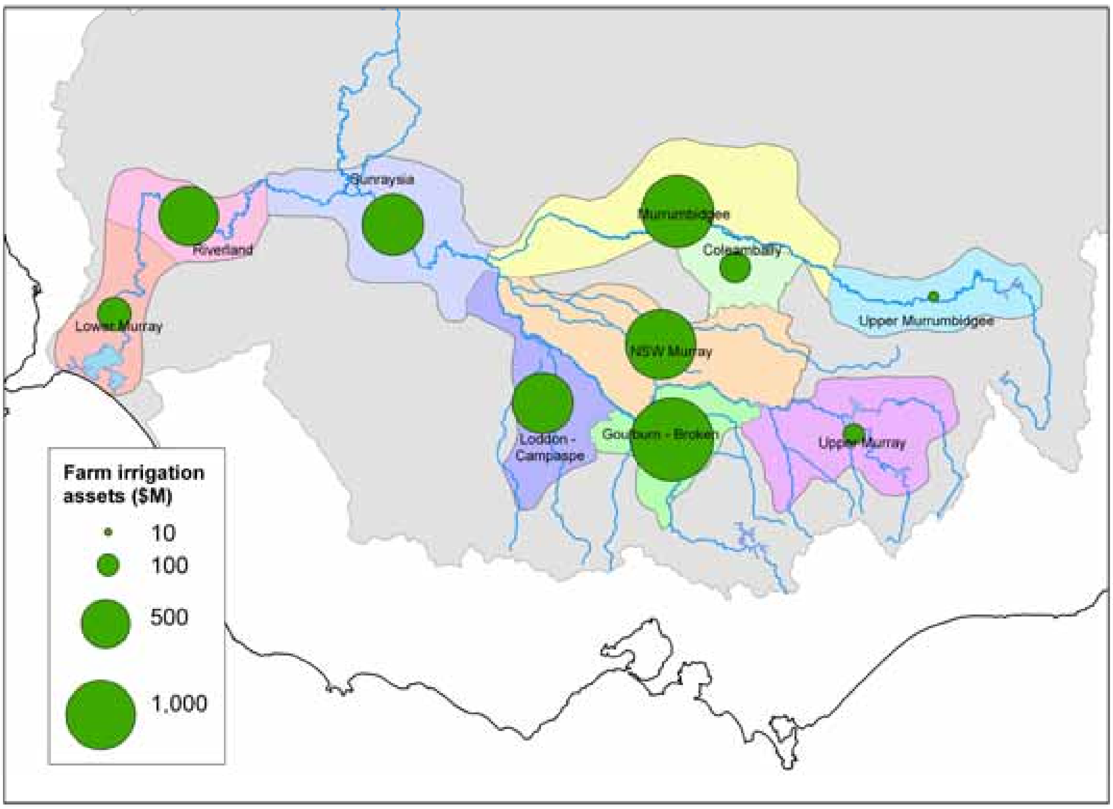


Figure 9 – Distribution across regions of the on farm irrigation assets valued at current replacement cost.

3.5 Methods of delivery to farm

The way water is delivered from the river to the farm gate varies from region to region and Table 5 below summarises these methods. In general, piped delivery systems to the farm gate are installed where gravity cannot be used and/or where the on farm irrigation system is predominantly sprinkler or drip systems. Piped delivery is not often used for surface irrigation methods because of the high flow rates required and hence large pipes and high pumping costs.

Region	Main method	Secondary
Upper Murrumbidgee	Direct pumping from the river into open channels and into sprinkler and micro systems	
Upper Murray	Direct pumping from the river into open channels and into sprinkler and micro systems	
Coleambally	Open channels (for all annual cropping and perennial horticulture	None
Murrumbidgee	Open channels (for all annual cropping and part of perennial horticulture)	Piped system (replacing open channels in perennial horticulture areas, increasing)
NSW Murray	Open channels	
Goulburn Broken and Loddon	Open channels (for all annual cropping and part of perennial	Piped system (replacing open channels in perennial horticulture

Campaspe	horticulture)	areas, increasing)
Sunraysia	Open channel system	Open channels increasingly being replaced
Riverland	Piped system	Open channels (almost phased out)
Lower Murray	Direct pumping from river to sprinkler and micro systems	Private community owned pipelines supplying connected properties with controlled systems

Table 5 – Main types of delivery system to the farm gate in the regions

3.6 Irrigation application methods

Comprehensive data on different irrigation systems is only available for South Australia. This has been compiled through local action planning (LAP) regional surveys. For the other regions, this information comes from farm survey and census data collected by ABS at a fairly coarse regional statistical basis. Figure 10 illustrates the differences between regions. Surface irrigation (border check or furrow) dominates in Victoria and New South Wales, while sprinkler and micro systems increase in the Sunraysia and South Australia.

The overall area distribution of application systems is in the proportions 83 : 10 : 7 surface : sprinkler : micro. In the Riverland, less than 3% of the irrigation area uses surface irrigation. As would be expected, the provision of controlled application systems requires significant change in the distribution system – this is what happened in the rehabilitation project for the Riverland during the 1980s and 1990s. The state government investment acted as a catalyst, engaging considerable irrigator investment to change the face of irrigation practice in the Riverland region. For a brief account of the rehabilitation process see Meyer and Bowmer (2004), in "Water Innovation – A new era for Australia".

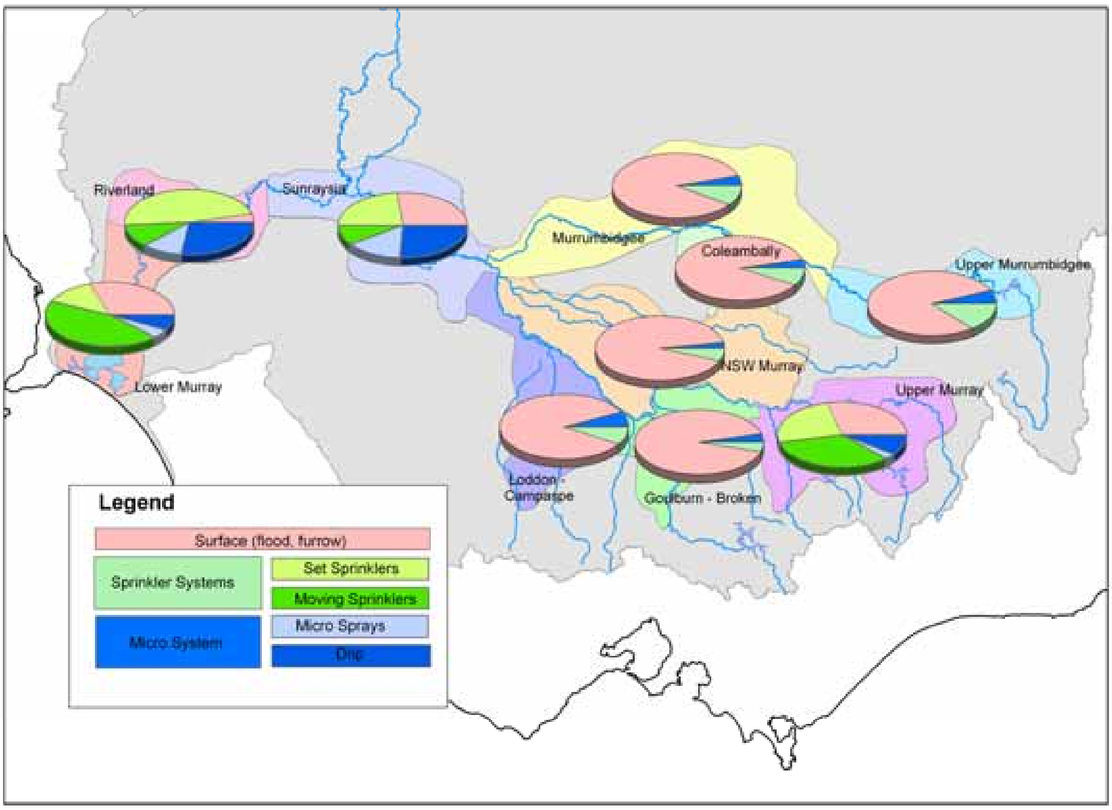


Figure 10 – Distribution of irrigation application systems by region.

Irrigation methods should have a high ‘field efficiency’, i.e. the ratio of water that is applied to the field to that which is retained in the root zone, available for crop use. In many situations the flexibility in timing and amount of water application may be controlled to a large degree by the regional or local water supply system. The potential for improving ‘field efficiency’ depends on the degree of understanding of the crop and soil system, the flexibility in management offered by the irrigation system and water supply, and the sensitivity of yield determining factors in providing an economic response to improvements in water management.

The choice of irrigation method should take into account the site conditions, the irrigation water quality, crops grown, labour availability and cost. Crop characteristics are very important in terms of establishment and tolerance of waterlogged or saline conditions.

The method of irrigation often affects crop quality in terms of marketability. For example, tomatoes are prone to low solids content when grown with drip irrigation compared with furrow irrigation. Onion crops are at risk of black mould if the foliage is frequently wetted as can be the case with some sprinkler irrigation setups.

Detailed information about the irrigation water application systems used on farms in the study region can be found in Appendix 2.

3.7 Drainage infrastructure and salt management in the regions

Drs Evan Christen and John Hornbuckle, CSIRO Land and Water, were major contributors to this section.

3.7.1 The need for drainage and salt management

Irrigation is not sustainable in the long term without drainage. Most irrigation areas have tried to avoid the cost of installing adequate surface and sub surface drainage. Surface drainage becomes critical in situations where there is variable rainfall, as is the case in the Murray and Murrumbidgee Basins. This is especially true on the flat, heavy clay soils of the Riverine Plains where winter rainfall and even episodic summer rain can delay and stop most farm operations and cause water-logged soil conditions.

Drainage past the root zone will occur with all irrigation, but especially with surface irrigation. The amount of drainage depends on irrigation practice, soil types, climatic conditions and crop types. Most irrigators have used the unsaturated layers below their crops to store drainage water, which will tend to join with local unconfined groundwaters. If the rate of soil profile drainage from irrigation exceeds the rate that water can move through the sub soil layers then saturated conditions ie transient water tables will result. If drainage is excessive, the underlying layers may become totally saturated and a continuous, unconfined aquifer will be formed that may rise to the soil surface.

This situation is commonly referred to as the development of a groundwater mound under the irrigated area. Continued drainage to the mound will cause it to spread laterally (albeit slowly) and adjacent areas will be affected by shallow water tables. With surface irrigation, water tables often rise until a new equilibrium is established, after which the water table fluctuates from the soil surface to around 3 m deep. A significant part of all irrigation areas in Australia are currently in this condition or approaching such equilibrium. 75% or more of the Murray Darling Basin (MDB) irrigation areas can be affected by shallow watertables (Murray-Darling Basin Commission , 1989). With drier than average years recently, the area affected is less than 75% but this could change under a wetter rainfall pattern. As water tables rise, stored salt within the soil layers will come into solution and may be added to by salt leached down from the upper soil layers. The general distribution across the Murray and

Murrumbidgee Basins of these underlying shallow (generally < 20m depth) groundwater salinities is shown in Figure 11.

To prevent the crop root zone becoming more or less permanently water logged either the rate of water addition (the intensity) will need to decrease or sub surface drainage will need to be installed. Decreasing the intensity of irrigation will only be effective in the long term if the intensity matches the dissipation rate of the groundwater system – a rate which is usually very slow. Apart from rice, irrigated crops do not grow well in water logged soils.

There is also the need to move the inevitable accumulation of salt away from the active root zone. All irrigation water contains salt. Most plants exclude salt as soil water moves into the roots and so as water evaporates, either through the plant or the ground surface, salt is left in the soil. The salts accumulate and if not moved away from the roots, will produce toxic or osmotic effects in plant cellular functions. Moving water through the soil profile to "pick up" and leach salts away from roots is essential for the long term maintenance of all irrigated crops. Restrictive layers that limit downward drainage of water or restricted drainage due to saturated lower layers will exacerbate the accumulation of salt. The occurrence of shallow water tables, particularly in irrigated areas predisposes them to increasing salinisation.

The rate at which salt accumulates in the upper soil layers is determined by the salt that is added in the irrigation water and that moved out of the root zone by leaching. Restricted leaching and more saline irrigation water will exacerbate salt accumulation. To overcome the soil saturation and remove accumulated salt subsurface drainage systems – usually horizontal pipe drains for perennial horticulture and pumping from tubewells or spearpoints in dairy pastures have been installed.

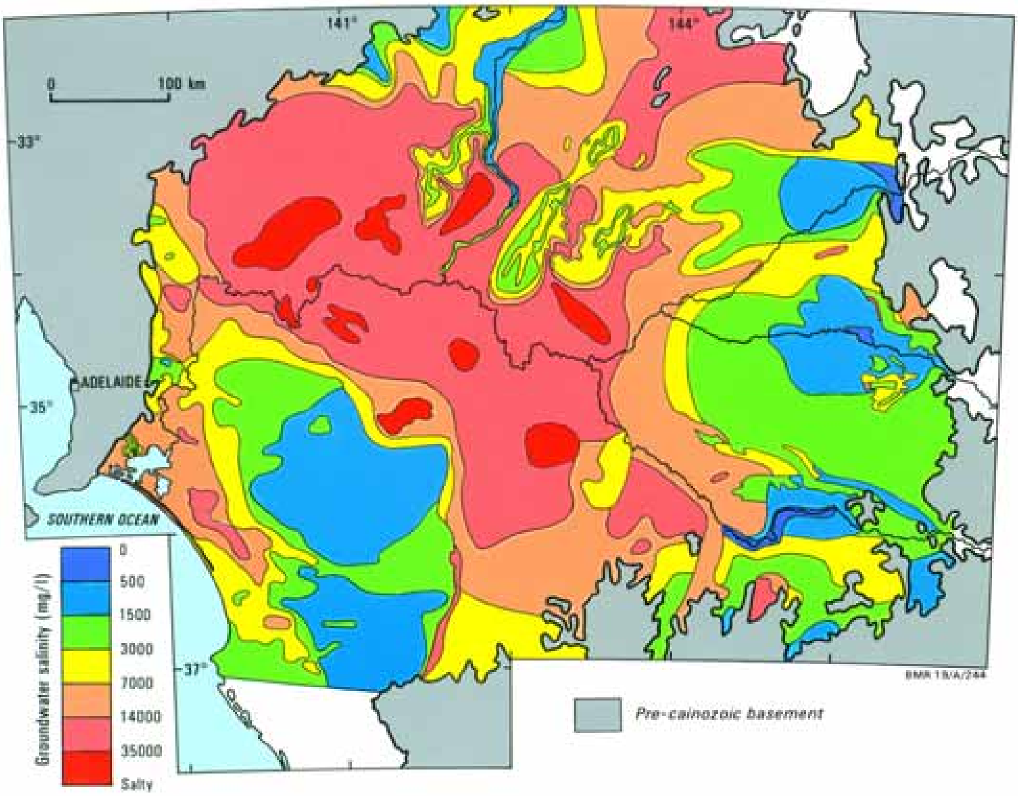


Figure 11 - Shallow groundwater salinity zones in the Mallee and Riverine sections of the Murray Basin. Shallow nominally means the top 20m of the regolith. Reproduced from "The Murray"

3.7.2 Drainage and salt management works

Shallow water tables, usually defined as those less than 2m from the ground surface, and increasing salinity in the upper soil profile now exist in many of the older irrigation areas in the study regions. These areas need considerable intervention in the form of sub surface drainage if the effects of water logging and increasing surface soil salinity are to be managed so that crop productivity is maintained.

The drainage information in Table 6 comes primarily from areas managed by irrigation companies. While this describes the majority of the area within our regional classification, it does not account for the entire drainage infrastructure within the regions. Therefore, the estimate of total area serviced with sub surface drainage (171,227 ha) is highly likely to be an underestimate. Our judgement is that it is more likely to be around 200,000 ha or about 17% of the total irrigated area. Similarly, the irrigated area with surface drainage of some form will be underestimated. Almost all (>80%) the irrigated area is serviced by some form of surface drainage.

Subsurface pipe drains being laid in the MIA (E.W.Christen)

Subsurface drainage has been the historical remedy for poor irrigation practice. Since the 1980s, however, more emphasis has been placed on improved irrigation practices. Since the 1990s most irrigation areas have had Salinity Management Plans or Drainage Management Plans or Land and Water Management Plans that aim to improve the sustainability of irrigation by improving drainage and improving irrigation water delivery and application efficiency.

In the following sections we will detail the purpose, extent and cost of the various subsurface drainage schemes across the regions. Much of this is extracted from the study by Christen and Hornbuckle (2002) who compiled information from six irrigation areas that are consistent with the regions defined in this study. These areas are:

1. Murrumbidgee and Coleambally Irrigation Areas
2. Mid Murray – NSW Murray region
3. Shepparton Irrigation Area in the Goulburn Broken region of Victoria
4. Kerang Area in the Loddon Campaspe region of Victoria
5. Sunraysia region of Victoria
6. Riverland in South Australia

Additional details about the implementation of subsurface drainage in the six irrigation areas relevant to our study are given in Appendix 3.

Region	Area irrigated (ha)	Area serviced by surface drainage (ha)	Area serviced by subsurface drains (ha)	Number of groundwater monitoring bores	Irrigated area with watertables <2m (%)	Salinity of irrigation water (EC)	Salinity of surface drainage water (EC)	Salinity of shallow groundwater (EC)	Salt retained (tonnes per annum)	Evaporation basin area (surface) ha
Upper Murrumbidgee (upstream of Narrandera)	4,000	nd	nd	nd	nd	nd	nd	nd	nd	nd
Murrumbidgee (MIA, Districts and Lower Bidgee)	263,000	208,696	10,000	854	33	104	412	2400 - 6500	92,099	60
Coleambally (includes Kerarbury Channel and outfall district)	75,000	95,000	40	887	24	132	754	200 - 2000	34,842	0
Upper Murray (including King, Kiewa, Ovens, Mitta Mitta)	14,000	nd	nd	nd	nd	nd	nd	nd	nd	nd
NSW Murray (Murray Irrigation Limited, west Corurgan)	321,000	245,000	48,000	1,452	2	44	290	100 - 125000	25,427	2,120
Goulburn Broken (including Yarrawonga canal)	275,000	236,050	69,792	927	55	53 - 83	978	nd	23,892	28
Loddon Campaspe (including National Kow Swamp channel)	197,000	140,422	10,065	1,680	28	83 - 550	600 -6000	nd	2,599	2,112
Sunraysia (SwanHill to SA border)	37,000	0	24,422	0	0	128	2,500	nd	9,538	4,260
Riverland SA	32,000	0	8,908	135	35	320	0	nd	28,646	4,731
Lower Murray SA (including Swamps and Lake supply)	26,000					1000		nd	nd	nd
Totals	1,243,000	925,168	171,227							13,311

Notes – nd = not determined, EC is in µS/cm which is 1000 x dS/m. Primary data source, ANCID (2004b) Benchmarking Report 2002/2003.

Table 6 - Regional summary of drainage and salt management works.

3.7.3 Comparison of subsurface drainage in the regions

Crops, irrigation and drainage problems

The major cropping systems, together with a generalised estimate of irrigation application amounts and the salinity level of the water are given in Table 7. The general trend is for less pasture and broad area crops and more perennial horticulture further downstream of the Murray. At the same time, irrigation water salinity levels tend to increase. The type of cropping and its associated value will affect the type of drainage system selected.

	Major crops	Average annual irrigation rate	Irrigation water salinity
		ML/ha	dS/m
Murrumbidgee/ Coleambally	Perennial & annual pasture horticultural crops– Rice	4 - 8 8 - 16 14	0.05 - 0.15
Mid Murray	Rice Perennial & annual pasture	14 1 - 6	0.06
Shepparton (Goulburn Broken)	Perennial pasture Perennial horticulture	10 7	0.05 - 0.15
Kerang (Loddon Campaspe)	Pasture for dairying Pasture for non dairy	6 - 10 2 - 4	< 0.4
Sunraysia	Perennial horticulture	6 - 14	0.3 - 0.6
Riverland	Perennial horticulture	6 - 12	0.3 - 0.8

Table 7 - Major crops and quantity and quality of irrigation water

Table 8 describes the development of drainage problems and current status in each region. Most problems are related to watertable rise from irrigation recharge, with the severity of the problem depending upon local hydrogeology and history of high watertables.

Irrigation region	Description of problem
Murrumbidgee/ Coleambally	Water logging caused by over-irrigation combined with wet winters saw water table problems develop within horticultural farms. Many supply channels had high seepage rates, causing additional water logging and salinity. High value crops sensitive to water logging and salinity, e.g. citrus, stone fruit and grapevines have been the focus of drainage in the past. Similar processes have occurred with the advent of rice growing, with dramatic rise in water tables. Net groundwater movement is towards less intensively irrigated areas which are at risk of salting over time. In summary, drainage problems in horticultural areas are mainly due to water logging, and in large area farms, salinity control is the main issue.
Mid Murray	Rising groundwater after clearing perennial vegetation for annual crops and pastures, application of irrigation water, seepage from district infrastructure and disturbance of natural drainage lines for public and private infrastructure. There is also a regional flow of groundwater from east to west. Groundwater salinity levels are extremely high, ranging from 0.5—66 dS/m.
Shepparton **(Goulburn Broken)**	Clearing native vegetation and irrigation have disrupted the natural hydrologic cycle within the Shepparton Irrigation Area and the Upper Shepparton aquifer and enclosing clay aquitards have become saturated. Groundwater levels are now within 2 m of the soil surface over much of the region resulting in waterlogging and salinity.
Kerang **(Loddon Campaspe)**	Groundwater 7-10m from the ground surface before irrigation development. Shallow water table established soon after the advent of irrigation and currently within 2 m of the soil surface over 65-75% of the region. Capillary rise of saline groundwater has resulted in secondary salinisation of 40% of the region, further exacerbated by regional groundwater flow in the deeper aquifer system at a depth of 50-120 m. In the north of the region high artesian pressure levels in the deep aquifer over most of the area, precluding natural drainage and resulting in a small upward flow of groundwater in low-lying areas.
Sunraysia	Furrow irrigation still used by 50% of irrigators in the area. Under furrow and sprinkler irrigation, perched watertable forms over the calcareous clay subsoil. Shallow fluctuating watertables lead to waterlogging and salinisation and subsurface drainage is regarded as essential in maintaining productivity under current irrigation systems. Hillside seepage problems occur where the deep sand of the dune crest gives way to a shallower soil further down slope.
Riverland	Irrigation applies five to six times more water than the annual rainfall. Groundwater mound development beneath the irrigated areas induced saline groundwater flows to the river and river valley with detrimental salinity and environmental impacts. Irrigated plantings in highland depressions were generally first areas to be affected and in some places seepage lakes formed. Perched water bodies were prevalent in soils with relatively impermeable subsoils. Reasons for these drainage problems are over-irrigation, inefficient irrigation methods and application, general rise in regional groundwater levels and lateral flow from adjoining irrigation areas.

Table 8 - Description of the subsurface drainage problem

Drainage methods and design criteria

Depending upon the type of drainage problem and crop type, the drainage objective will vary, as will the drainage method. The drainage objective and method are outlined in Table 9 and the ownership and operation of the subsurface drainage system is given.

Irrigation Region	Drainage method	Drainage objective	Ownership
Murrumbidgee/ Coleambally	Horizontal drains or vertical spearpoints for perennial horticulture, vertical for other crops, deep pumping for regional pressure control	Watertable control and subsequent prevention of soil salinisation for perennial horticulture, salinity control for other crops	Landholders (Private) for horizontal and water management agencies for vertical
Mid Murray	Shallow vertical with evaporation basin	Watertable control and subsequent prevention of soil salinisation	Murray Irrigation Ltd
	Shallow vertical	Irrigation supply and watertable control	Murray Irrigation Ltd (10) and landholders (150)
	Deep vertical	Irrigation supply	Landholders (Private)
Shepparton (Goulburn Broken)	Vertical 5-20 m deep protecting 100-200 ha each for perennial pasture and horizontal drains or spearpoints (~25 ha each) for perennial horticulture	Salinity control for pasture, watertable and salinity control for horticulture	Private (by farmers) if conjunctive water use to supplement surface irrigation supplies. Public (by water management agency).
Kerang (Loddon Campaspe)	Vertical, 5-15 m deep, protecting perennial pasture and experimental horizontal drains 70 m apart, also relief of deep artesian pressures	Salinity control	
Sunraysia	Horizontal drainage, interceptor drains on slopes, grid 13-40 m apart.	Watertable control and subsequent prevention of soil salinisation	Private (Landholders)
Riverland	Horizontal drainage, grid pattern, 10-30 m apart	Watertable control and subsequent prevention of soil salinisation	Landholders (Private)

Table 9 - Drainage objective, method and ownership

Pump for subsurface drainage by vertical drains (J.W. Hornbuckle)

Depending upon the drainage objective and method, the drainage design criteria will vary including; the target watertable depth after irrigation or rainfall and drainage coefficient. These, together with the actual long term drainage rate, are given in Table 10.

Region	Drainage type	Target watertable depth	Design drainage coefficient	Actual long term drainage rate
			(mm/day horizontal and ML/ha/yr vertical)	(ML/ha/yr)
Murrumbidgee/ Coleambally	Vertical		Spearpoints for horticulture 1ML/ha/yr	~3 - 4 (spearpoints ~3)
	Horizontal	0.45 - 0.75 m after 3 days for perennial horticulture	5 mm/day when watertables are at 0.3 m depth	0.5 - 2,
Mid Murray	Vertical	>1.5 - 2.0 m	0.6 – 1.0 ML/ha/yr	~ 0.3 – 0.6
	Horizontal			
Shepparton (Goulburn Broken)	Vertical	None	0.8 (over 120 days – 1ML/ha/yr) 0.4 (for 2 periods of 60 days – 0.5ML/ha/yr)	Private ~ 3, Public 0.5
	Horizontal			
Kerang (Loddon Campaspe)	Vertical		0.25 - 0.5	3 - 4
	Horizontal	>1.2 m (<0.1 mm/d capillary rise) Also relief of artesian pressures	Experimental horizontal drains - 2.5 with watertable at 0.3 m, however 0.8 may be adequate,	1 – 2,
Sunraysia	Vertical	One week after irrigation–watertable at 0.9 - 1.1 m	2 - 5	1 - 1.5 (tile)
	Horizontal			
Riverland	Vertical	One week after irrigation –watertable at 0.9 - 1.1 m	2 - 5	1 - 2 (catchment basis)
	Horizontal			

Table 10 - Target design criteria for subsurface drainage systems used in Australia

Drainage water quality and disposal methods

Drainage water quality will be affected by groundwater quality (Table 11) which will then affect the choice of drainage water management method.

	Groundwater quality (dS/m)		Drainage water quality (dS/m)
	Shallow (< 30m)	**Deep (> 30m)**	
Murrumbidgee /Coleambally	1 - 20	0.5 - 1	Horizontal 2 –12 Vertical 5 - 20
Mid Murray	0.5 - 66	0.5 - 10	Public 23 Private 0.5 - 3
Shepparton	1 – 10 (and higher)	0.5 – 10 (and higher)	Private up to 3.5 Public up to 10
Kerang	30 - 50	1 —10	20 - 50
Sunraysia	2 - 4	20 - 50	2 - 5
Riverland	1.6 - 3.9	4.7 - 47	1.6 - 47

Table 11 - Groundwater quality in subsurface drainage

Due to varying drainage water quality and cropping systems which affect re-use possibilities and various limitations on discharge into rivers, a number of disposal options have been implemented (Table 12).

	Methods used to store, evaporate and reuse drainage waters
Murrumbidgee	8% to river, 4% to evaporation basins, 88% to surface drainage system which is reused in Wah Wah Irrigation District.
Mid Murray	Mainly discharge into evaporation basins. Small amount of discharge into the irrigation supply system during the irrigation season. Discharge off farm of groundwater from private pumps is not permitted.
Shepparton	Private pumps - conjunctive reuse (mi– to 0.8 dS/m, public pumps - irrigation and drainage channels for reuse (mix to 0.5 dS/m), that not reused goes to river. Drainage water >10 dS/m to evaporation basin.
Kerang	Very saline drainage to evaporation basins, less saline waters used for conjunctive reuse.
Sunraysia	Evaporation basins
Riverland	88% to floodplain basins, 11% to highland disposal basins, <1% to river. Also a reuse scheme on irrigated lucerne in Qualco district using water up to 3.5 dS/m

Table 12 - Drainage disposal methods

System costs, management and monitoring

With different drainage methods and disposal costs, the overall cost of drainage will vary widely. How these costs are shared between direct and indirect beneficiaries is also important. Table 13 gives an indication of the installation and operational costs of subsurface drainage and also cost sharing arrangements.

	System type	Capital costs		Operating costs		
		Installation	Cost sharing	Per ha/yr	Per ML/yr	Cost sharing
Murrumbidgee/ Coleambally	Horizontal	$2,800	All Landholder (Fixed interest loan available from State)		$0.90	All landholder
	Horizontal plus evaporation basin	$3,800	All Landholder (Fixed interest loan–available from State)		$25 - 50	
Mid Murray	Shallow pumping to evaporation basin	$615/ha	NSW and Federal Govt	$7	$28	O&M paid by landholders
	Shallow pumps	$200,000 for 250 ha	Subsidy up to 70%	$10	$10	O&M paid by landholders
	Deep pumps	$100-200,000	Landholder	na	$10	O&M paid by landholders
Shepparton (Goulburn Broken)	Vertical	$250/ha ($40-50K investigation/ $70-80K capital)	Public pumps State govt., private pumps provided with subsidy up to 65%			Costs shared between local beneficiary (40-50%), all irrigators (40-80%) and local government (17%)
Kerang (Loddon Campaspe)	Extended well points	$1380/ha	All Water Management Agency (Experimental)			
	Horizontal (60m)	$4230/ha				
	Horizontal (120m)	$2280/ha				
	Moles	$3350/ha				
	Deep pumps and Serial Biological Concentration	$884/ha				
	Deep pumps (winter)	$680/ha				
	Horizontal and evaporation basin	$5438/ha				
Sunraysia	Horizontal	$4500/ha	On farm by farmer, community pipe collector main system by government	$36	$6	Cost of O&M of evaporation basins met by a system of tariffs, based on a "service" fee a "per ha" fee and a "per ML of irrigation use" fee.
Riverland	Horizontal	$5000/ha (minimum)	On farm by farmer, community pipe collector main system by Irrigation Trusts			

Table 13 - Summary of drainage installation and operational costs

Management and monitoring arrangements for subsurface drainage systems are highly varied (Table 14) depending upon the type of drainage system, ownership and disposal method.

Region	Management and monitoring
Murrumbidgee/ Coleambally	Horizontal - managed by farmers (sometimes turned off), vertical by Department of Infrastructure, Planning and Natural Resources (DIPNR). Monitoring - horizontal drains surveyed every ten years and ad hoc monitoring, vertical by DIPNR - volumes/quality and drawdown. Piezometers measured bi-annually by irrigation companies.
Mid Murray	Murray Irrigation Limited (MIL) monitors 1500 shallow piezometers, the DIPNR monitor deep groundwater observation bores. MIL manages the evaporation basin scheme and ten other vertical pumps operated to control groundwater levels. Farmers manage the operation of private shallow and deep groundwater pumps. DIPNR is responsible for the monitoring of volumes of groundwater extracted from licensed bores.
Shepparton	Private pumps not previously directly monitored. Groundwater plan being implemented, including metering of private pumps and monitoring of pumped groundwater salinities. Public pumps by water management agency. Need regular and consistent pumping for salinity control. 2000 observation bores monitored.
Kerang	Mostly experimental installations.
Sunraysia	No management undertaken. Monitoring at end of system not individual farms.
Riverland	No on farm reuse management undertaken. Monitoring at end of each catchment system, not individual farms.

Table 14 - Management and monitoring of drainage systems

These drainage practices have been developed according to local conditions and hence were appropriate for their area. Often, however, the design of drainage systems, particularly horizontal drainage, has not changed since the original need was established in the 1920s – 50s. Drainage criteria need to be adapted in light of changed irrigation practices and other advances in irrigation agronomy and supply management that should result in a lower overall drainage requirement.

3.7.4 Drainage trends in the Murray and Murrumbidgee Basins

As indicated above, subsurface drainage design and management across the Murray and Murrumbidgee Basins varies widely. It is evident that in some areas salinity and waterlogging will continue to develop until remedial measures are implemented. Subsurface and surface drainage, improved irrigation practices and changes in land use management are inter-related so it is important to consider them in an integrated way to develop sustainable irrigation.

The main areas drained are those associated with higher value products, principally perennial horticulture, perennial pasture for dairying and some crop areas where salinity or shallow water tables severely limit productivity. Thus, subsurface drainage has generally been targeted at those crops where the returns are greatest and any loss of productivity due to waterlogging and salinisation is most significant. These schemes are usually partially or completely paid for by the landholder. However, the extensive Wakool-Tullakool subsurface drainage scheme in the NSW Murray region was funded entirely by government. Through groundwater pumping, the scheme provides comprehensive drainage over many thousand hectares for a mix of field and fodder crops.

The intensity of irrigation varies greatly from region to region depending upon cropping and climate. Most regions have some evidence of improved water delivery efficiency and application efficiency, a trend that is vital to reduce drainage volumes. However, most irrigation areas have developed groundwater mounds, some coming close to the surface with water logging evident in lower lying areas and after rainfall, particularly winter rainfall.

It is not clear for any of the regions whether improved irrigation management could have avoided the problem although it will certainly have delayed it. Waterlogging is a significant risk in perennial horticulture and hence drainage for watertable control has been implemented in these areas, which has also controlled soil salinisation. Pasture, which is not as sensitive to waterlogging, has also been drained for watertable control and, in some cases, for salinity control. In the Shepparton region, sub surface drainage of pasture areas is not managed to achieve a particular watertable criteria, rather a leaching fraction is extracted annually. Other regions such as Kerang have also identified a lack of clear drainage criteria for long term salinity control under current land use and irrigation management systems.

By world standards, most surface supply in the regions is of good quality (<0.4 dS/m, < 400 EC, Table 5). Thus, irrigation induced salinity is generally due to shallow saline watertables rather than the application of poor quality irrigation water. Only in Sunraysia, Riverland and particularly the Lower Murray in SA is there occasional high salinity irrigation water coming from the river.

Subsurface drainage pump (pipe drains) discharging to surface drain in the MIA (E.W. Christen)

Drainage criteria for perennial horticulture, especially in the Murrumbidgee, Riverland and Sunraysia areas, aim to control very shallow watertables (< 1m). This has resulted in drainage design coefficients of 2 – 5 mm/year and high drainage volumes from these areas. However, most regions report decreased drainage volumes in recent years shown by reduced or declining rates of rise in underlying groundwater levels. This may be attributed to dry climatic conditions but also improved irrigation efficiency. More perennial horticulture is being converted to, or installed with, micro irrigation systems. Subsurface drainage for these areas should therefore be designed primarily for salinity control. There has been limited experimentation into the optimum design and management to achieve adequate salt control with lower cost drainage systems and lower drainage discharges.

While sub surface drainage below the root zone is needed in all irrigation areas, the question that must be addressed is "drain to where"? In areas of low intensity irrigation it may be possible to match drainage rates to the natural dissipation of underlying groundwaters. However, if underlying groundwaters have direct connection with adjacent river systems then irrigation-induced saline discharges to the river will be evident – as is the case in the Riverland.

Installed drainage systems, either vertical or horizontal, can generate large volumes of saline waters. Many areas are now reviewing the management of all subsurface drainage systems with a view to reducing drainage volumes due to the adverse effects that salt additions have on rivers, lakes, land and groundwater. While some drainage water of lower salinity is reused by adding to supply waters, as in Shepparton, other areas encourage reuse on lucerne and tree lots, while many regions discharge to evaporation basins. The extent and operation of these basins in the regions of this study is documented in the report by Simmonds et al (2000) and others.

It has become increasingly apparent that evaporation basins are, in effect, salt storage areas, and their impact on surface and sub surface soil, land and groundwater needs to be carefully assessed and monitored. The real and perceived adverse effects of evaporation basins, particularly the large ones in the western regions (Sunraysia and Riverland) is a driving motivation for reducing drainage volumes.

The drainage method adopted depends upon the local hydrogeology. Usually, pumping of the upper unconfined aquifers is undertaken where the material is sufficiently permeable. Horizontal drains have been used in the less permeable materials or where drainage problems are very localised, e.g. in small depressions or break of slope areas. The costs of these systems vary enormously (Table 13). Groundwater pumping from spear point systems generally has a capital cost of about $250/ha protected whereas horizontal drains cost about $3000-5000 per ha. This reflects the intensity of drainage that is required when protecting horticultural crops.

Future drainage requirements

It was estimated in 1987 that 96,000 ha of irrigated land in the Murray-Darling Basin were visibly affected by soil salinisation and that 560,000 ha had water tables within two metres of the surface (Murray-Darling Basin Ministerial Council, 1987). It was predicted that by the year 2015, 869,000 ha of irrigated land would be salinised or waterlogged due to high water tables. This represents about 60% of the land presently irrigated in the Basin (1.47 million ha; Murray-Darling Basin Commission, 1999).

However, recent surveys in New South Wales suggest that these predictions are too high. There were high watertables in around 70-80% of the irrigated area in the late 1980s, this has dropped to 30-50% currently. This is probably due to a number of reasons:

1. Improved irrigation practices, reduced irrigation water availability and low rainfall.
2. The below average seasonal rainfall conditions experienced within the region in recent years and the associated reduced irrigation availability, have resulted in much decreased volumes of recharge.

3. Increased levels of shallow and deep groundwater use, both from existing pumps and the installation of new pumps. However, little information is available to quantify the volume of water extracted, the quality of the water or on what land use the groundwater is being applied.
4. Implementation of the Murray–Darling Basin Cap on river extractions will continue to promote greater irrigation water distribution and application efficiency and, hence, less recharge. It also provides an incentive to landholders to increase the extraction from both shallow and deep groundwater bores.

Surface drainage

It is likely that the area serviced by surface drainage will expand until all irrigated areas have a comprehensive surface network. The South Australian irrigation areas are probably the only exception due to the topography. The MIA and CIA are fully serviced by an integrated surface drainage network. Areas of the NSW Murray and the Shepparton region require completion of the surface network. This work is underway in the scheduled Land and Water Management Plan activities.

Subsurface drainage

With the recent decline in the area affected by watertables close to the surface, the requirement for subsurface drainage is much reduced. More controlled irrigation systems, particularly in perennial horticulture, means that new subsurface drainage is likely to be restricted to small pockets where soil salinisation occurs for reasons of topography or historical irrigation practices. There are areas that are affected by low levels of soil salinity e.g. southern CIA, but the production losses on the annual crops grown are not significant enough to offset the high costs of subsurface drainage. These marginal areas for subsurface drainage could be drained should there be a change in conditions that results in higher economic losses or the cost of drainage is reduced. The area of the Murrumbidgee/Murray valley that is likely to be in this condition is likely to be upwards of 10,000 ha.

Drainage disposal is a key constraint to current and future development of subsurface drainage. This has led to landholders adopting irrigation and agronomy that minimises recharge rather than drainage systems. The hope being that the natural drainage to the groundwater system will provide adequate leaching. This tactic is likely to be successful under the current low rainfall conditions. Should we return to wetter rainfall cycles then much horticulture that has been developed on heavier soils may experience drainage difficulties. Luckily the major expansion in horticulture has been in vineyards and grapevines that are relatively tolerant of waterlogging. However, if some wetter climate cycle in the future should cause shallow watertables to persist and salinity becomes an issue, or agronomy be severely affected e.g. inability to harvest, then a portion of the new horticultural expansion would require drainage. This would be an area likely to exceed 10,000 ha.

This issue of economic viability relates to the economic productivity of the current farming systems. This suggests that research priorities related to subsurface drainage need to be aimed at cost reduction. Tackling drainage issues with changed land use and improved irrigation practice, using the concept of net recharge management (Khan, Xevi & O'Connell 2003), needs to be further researched to establish whether this will provide long-term salinity control.

4 People, production and income

4.1 Population, towns and origins

The regions we identified have a total population of more than 570,000. These people tend to be aggregated in a series of medium sized towns and small cities that service the irrigated areas and often the immediate adjacent rain fed districts. Figure 12 indicates the distribution and size of the population centres in the south eastern part of Australia. At first glance there does not appear to be a relationship between larger population centres and the expected larger activity and population in irrigated regions. However, the distribution of population centres in areas with less than 500 mm of annual rainfall is clearly associated with irrigated regions. In other words, larger towns exist in the low rainfall areas because of irrigated activity.

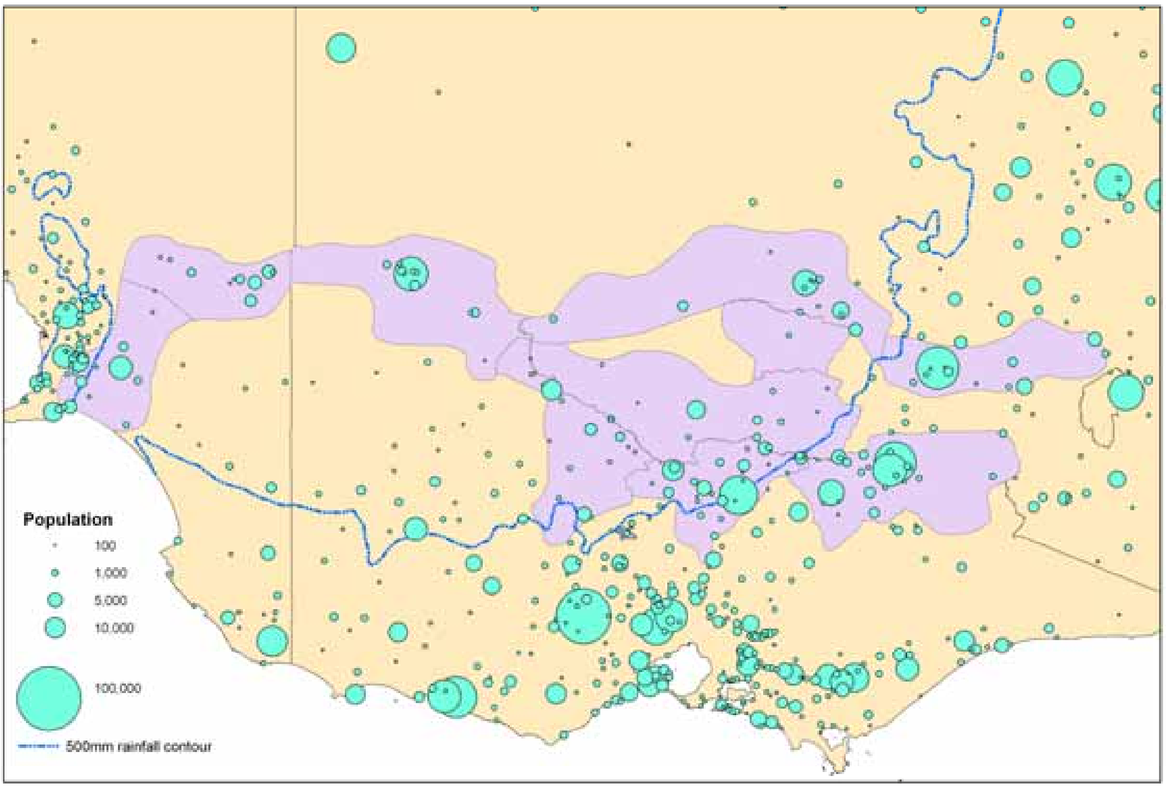
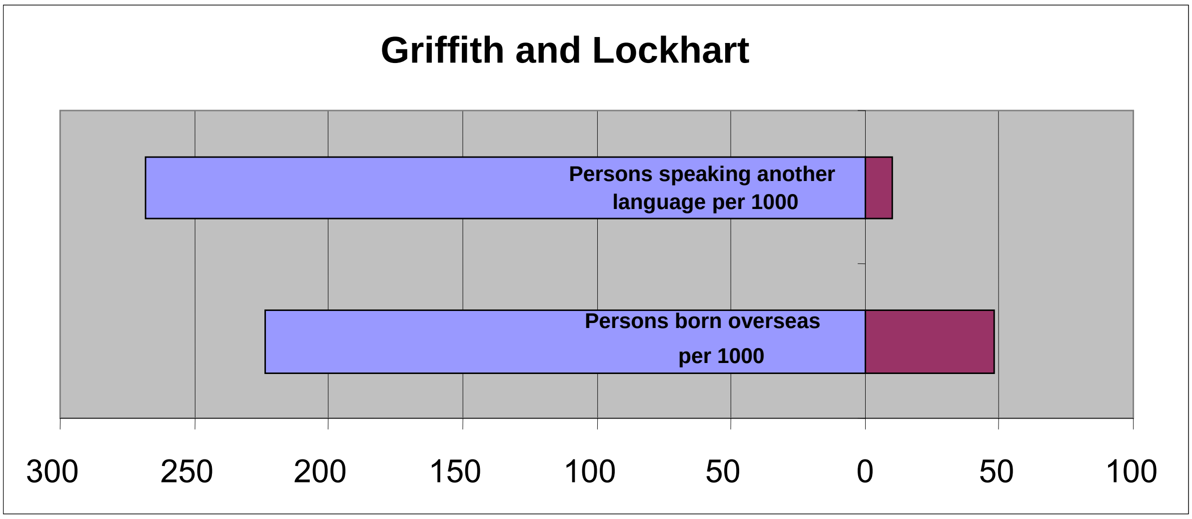
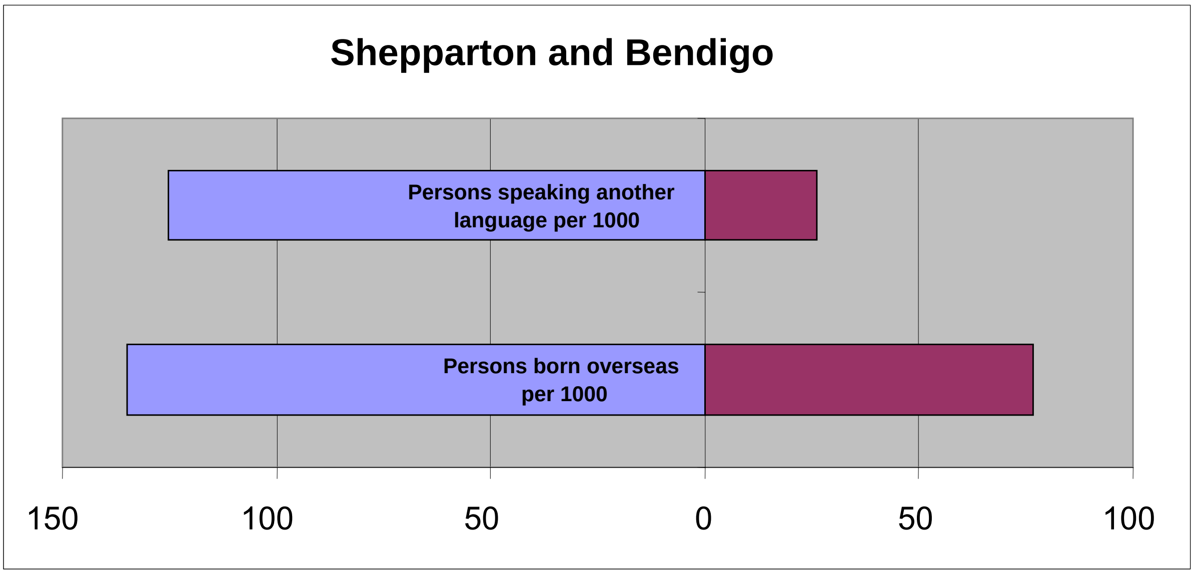


Figure 12 – Distribution and size of population centres in south eastern Australia. Note: the capitals, Adelaide, Melbourne and Canberra are not represented because their sizes would overshadow the other areas.

Casual observation in the irrigated regions would indicate a diverse mix of people from many countries. This is borne out by the census statistics that show (Figure 13) irrigated districts tend to attract many who have recently emigrated. The three irrigated districts have people who have come from more than twenty five different countries. In essence, irrigated districts tend to offer opportunities for new Australians and, as a consequence, irrigated towns generally have a high diversity and mix of peoples.


Griffith and Lockhart
Persons speaking another language per 1000
Persons born overseas per 1000
300
250
200
150
100
50
0
50
100


Shepparton and Bendigo
Persons speaking another language per 1000
Persons born overseas per 1000
150
100
50
0
50
100

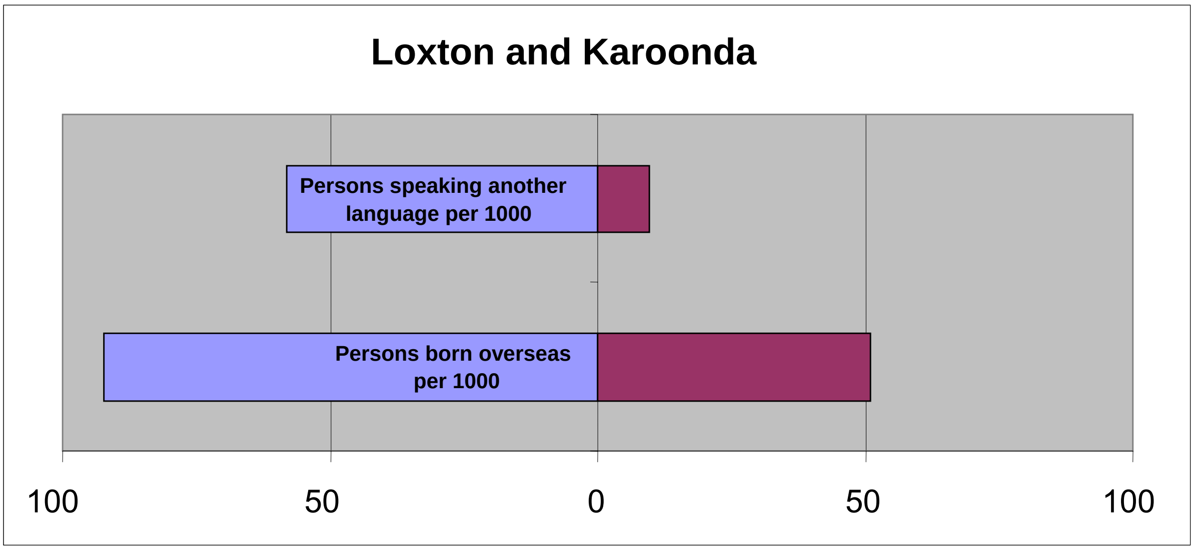

Loxton and Karoonda
Persons speaking another language per 1000
Persons born overseas per 1000
100
50
0
50
100

Figure 13 – Comparison of countries of origin and native language distribution between three districts, one irrigated and a nearby rain fed district. (Irrigated district in blue, rain fed district in purple.)

A perception voiced from irrigated areas is that their population generally has more people in the younger age groups. While there is no doubt that there are more people in the irrigated districts (see section 4.3 below), the census data on age demographics for the three pairs of irrigated and rain fed districts does not show this. Table 15 indicates that there is a greater proportion of people (8% more) under forty years in Griffith compared with Lockhart In both Shepparton compared with Bendigo and Loxton relative to Karoonda there is 2.4% more people under forty. In general terms, the differences in age demographics between irrigated and rain fed districts in our regions are small.

Age	Griffith	Lockhart	Shepparton	Bendigo	Loxton	Karoonda
0 -19 years	31.5	30.8	31.0	29.8	28.1	27.6
20 - 29 years	13.7	8.8	12.6	12.8	10.6	8.3
30 - 39 years	15.3	12.8	14.8	13.4	14.1	14.5
40 - 49 years	13.7	15.1	14.6	14.8	15.4	16.2
50 - 69 years	17.6	21.4	18.4	19.1	20.6	23.6
70 and older	8.3	11.2	8.6	10.2	11.1	9.8

Table 15 – Age demographics shown as % in each age class for the three comparison districts (Griffith and Lockhart, Shepparton and Bendigo and Loxton and Karoonda). Data from ABS 2002/2003 census.

4.2 Summary for irrigated regions

Table 16 provides a summary of the essential features of the irrigated areas. The regions have a population of more than half a million, many of whom are associated either directly with irrigation or through dependent services and value-adding industries.

The number and size of irrigation farms is strongly related to type of irrigation activity – larger area farms for pasture and crops, smaller, more intensively managed units with grapes and fruit.

Only about one third of the potential area is irrigated within any irrigation season – particularly in regions with a high proportion of pastures and annual crops. As expected, this flexibility is greatly reduced in Sunraysia and Riverland where perennial crops predominate.

Region	Population	Number of irrigated farms	Possible irrigated area ('000ha)	Irrigated area 00/01 ('000ha)	Surface water diversion 01/02 (GL)	Estimated irrigation water requirement (GL)	Off farm irrigation infrastructure value ($million)	Capital stock in irrigated farms ($million)	Revenue from irrigated activity ($million)	Total regional revenue ($million)
Upper Murrumbidgee (upstream of Narrandera)	68,585	269	10	4	39	19	10	21	5	241
Murrumbidgee (MIA, Districts and Lower Bidgee)	48,248	2,408	658	263	1,638	1,532	397	1,086	497	743
Coleambally (includes Kerarbury Channel and outfall district	2,439	453	410	75	662	447	120	196	96	155
Upper Murray (including King, Kiewa, Ovens, Mitta Mitta)	138,460	785	15	14	21	53	10	95	46	354
NSW Murray (Murray Irrigation Limited, west Corurgan)	33,091	2,500	1,013	321	2,092	2,271	730	1,030	309	615
Goulburn Broken (including Yarrawonga canal)	115,682	7,000	520	275	2,167	2,031	1,151	1,432	871	1311
Loddon Campaspe (including National Kow Swamp channel)	34,119	5,462	352	197	1,029	1,417	576	767	248	544
Sunraysia (SwanHill to SA border)	57,415	2,475	53	37	467	213	561	784	423	552
Riverland SA	33,968	3000	35	32	311	247	193	732	515	615
Lower Murray SA (including Swamps and Lake supply)	51,023	712	29	26	183	137	25	234	125	296
Totals	583,030	25,064	3,095	1,244	8,608	8,367	3,773	6,377	3,135	5427

Table 16 – Summary of regional characteristics associated with irrigated agriculture

4.3 Comparison with adjacent rain fed regions

There is little doubt that irrigation increases the level of agricultural activity and associated services and value-adding industries. But how much does this activity increase relative to what might be generated without irrigation i.e. as rain fed agriculture? To examine this we made comparisons between selected irrigated districts and nearly adjacent, but comparable, rain fed regions. The data used was from the Australian Bureau of Statistics collected on a statistical local area (SLA) basis. We chose three sets of districts, one in each of the three states that represent the major agri-ecological zones – Loxton/Karoonda in SA, Griffith/Lockhart in NSW and Shepparton/Bendigo in Victoria.

Figure 14, **Figure 15** and **Figure 16** compare the proportional level of activity of each pairing. In general terms, the presence of irrigated production within a district increases the level of activity by three to five times as shown by any indicator. Thus, the number of people in the district reflects this activity. The addition of irrigation water increases the resource base of the district which in turn enables and sustains a higher level of activity and an associated population.

While the level of activity is clearly increased, is there any evidence that this activity is more intense on a per capita basis? To explore this we collated data for the paired regions and expressed it per thousand head of population. The results of this are shown in Figure 17, Figure 18 and Figure 19. Across the three regions there is no significant difference in the unemployment rate (34 /1000 people in irrigated, 39/1000 people in rain fed districts) while there is a small increase (6%) in those employed in irrigated districts (603 /1000 people in irrigated, 570/1000 people in rain fed districts). The indication, with respect to agricultural service businesses, is that there are clearly more in total because there is more activity in the irrigated districts, although there are fewer of these businesses per thousand people. We interpret this to mean that the service businesses are generally bigger in the irrigated districts. For those activities labelled as community “services” (communication, finance, insurance, health, and recreational), there is a clear difference between irrigated (44/1000 people) and rain fed (26/1000 people) districts. Presumably, the larger population in irrigated districts encourages and supports a greater range of services both in total and in intensity i.e. more per 1000 people. People in irrigated districts enjoy greater access to services relative to those in adjoining or near by rain fed districts.

People in irrigated districts are often aware of and promote their districts as important tourist and visitor destinations, primarily because of the attraction with associated river systems and production activities such as wineries. While accurate numbers for regional tourism are often hard to obtain, the indication from census data is that there are three to four times more tourist visits than to adjacent rain fed areas but the intensity or rate of visitation on a population basis is not greatly different – 45/1000 people in irrigated districts relative to 39/1000 people in rain fed districts.

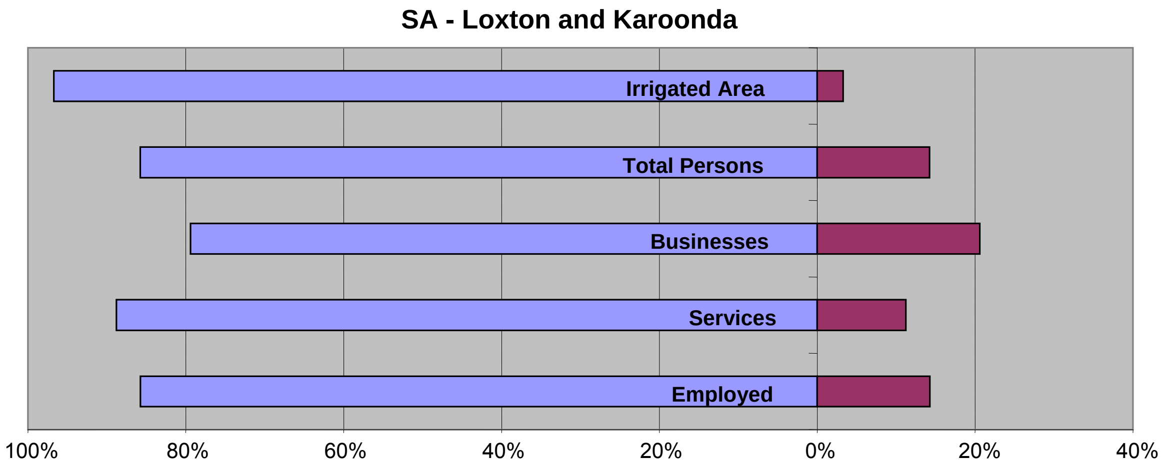


Figure 14 – Proportion of total measured activity in an irrigated district (Loxton) and an adjacent rain fed district (Karoonda) in South Australia. (Irrigated district in blue, rain fed district in purple.)

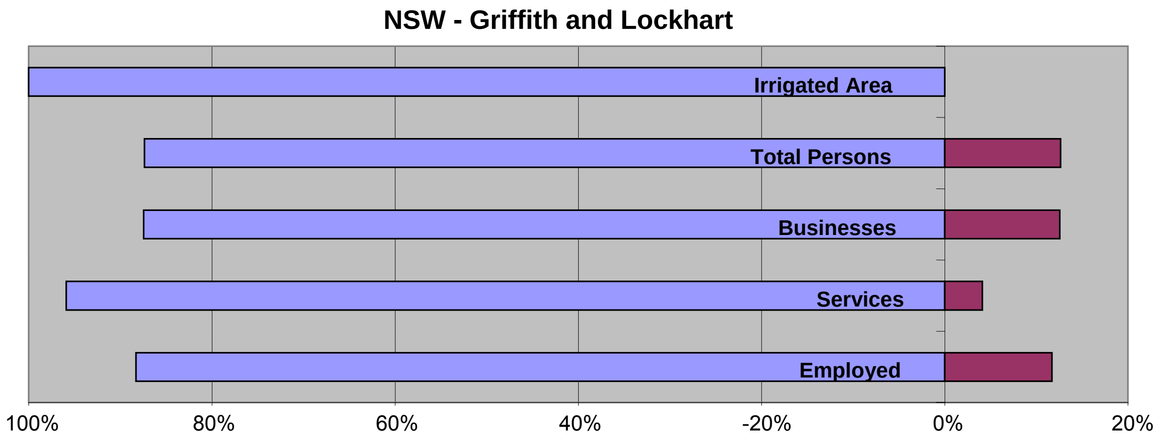


Figure 15 – Proportion of total measured activity in an irrigated district (Griffith) and a near by rain fed district (Lockhart) in New South Wales. (Irrigated district in blue, rain fed district in purple.)

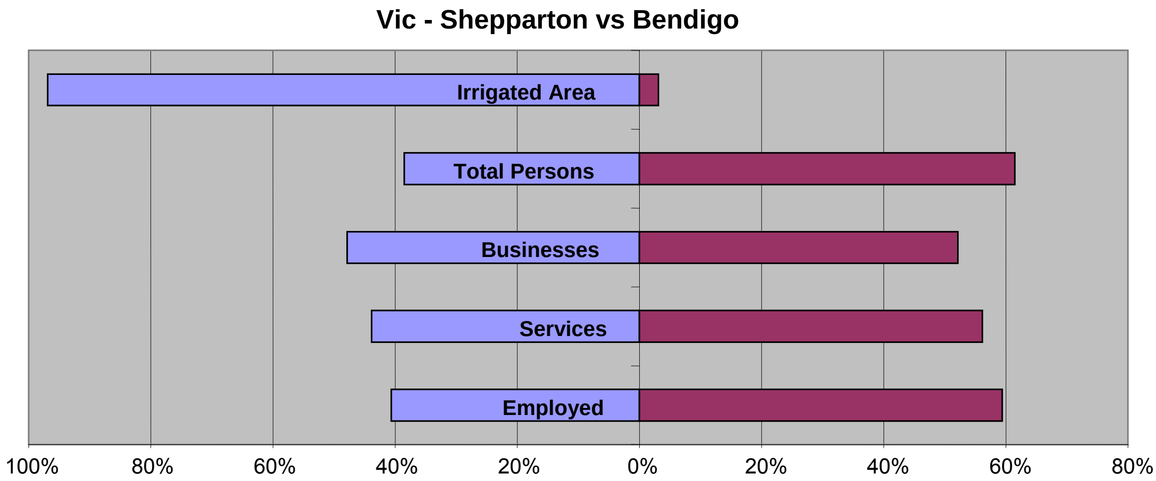


Figure 16 – Proportion of total measured activity in an irrigated district (Shepparton) and a near by rain fed district (Bendigo) in Victoria. (Irrigated district in blue, rain fed district in purple.)

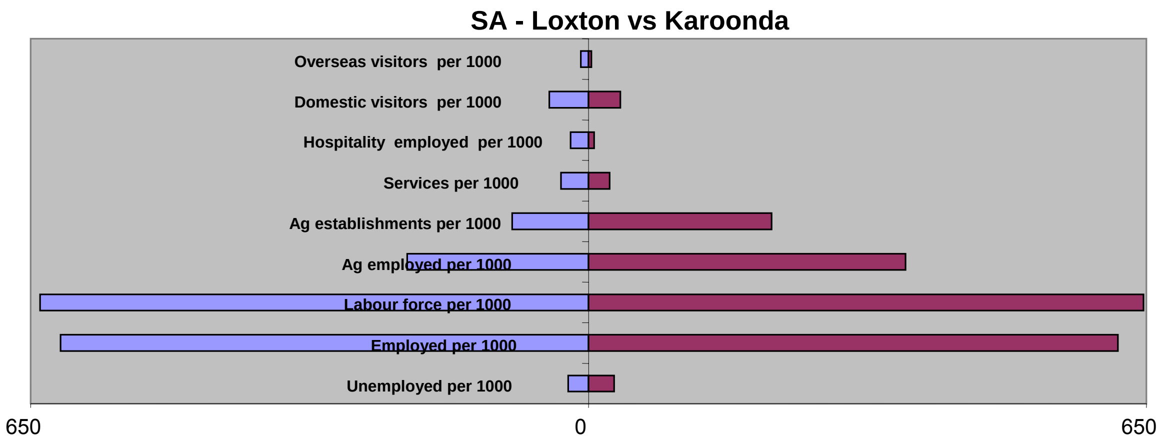


Figure 17 – Level of measured activity per thousand head of population ("intensity of activity") in an irrigated district (Loxton) and an adjacent rain fed district (Karoonda) in South Australia. (Irrigated district in blue, rain fed district in purple.)

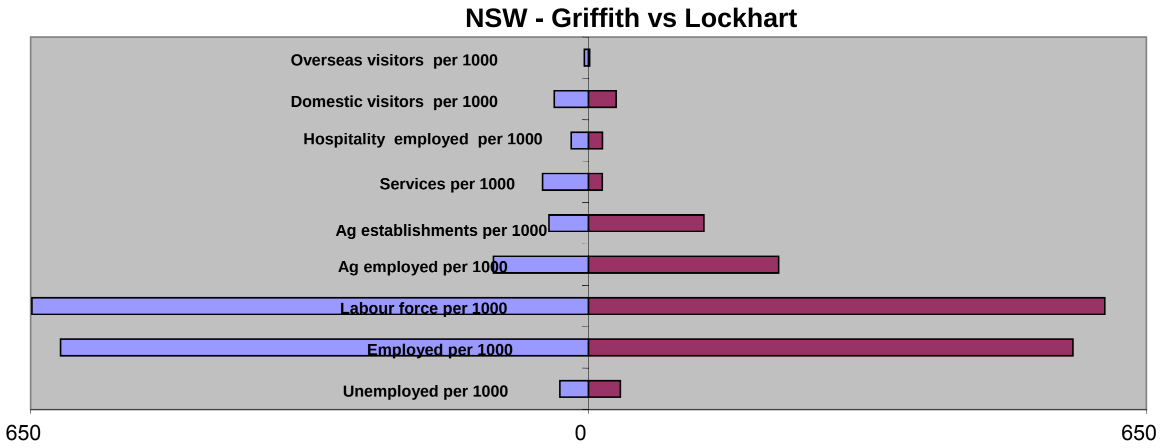


Figure 18 – Level of measured activity per thousand head of population ("intensity of activity") in an irrigated district (Griffith) and a near by rain fed district (Lockhart) in New South Wales. (Irrigated district in blue, rain fed district in purple.)

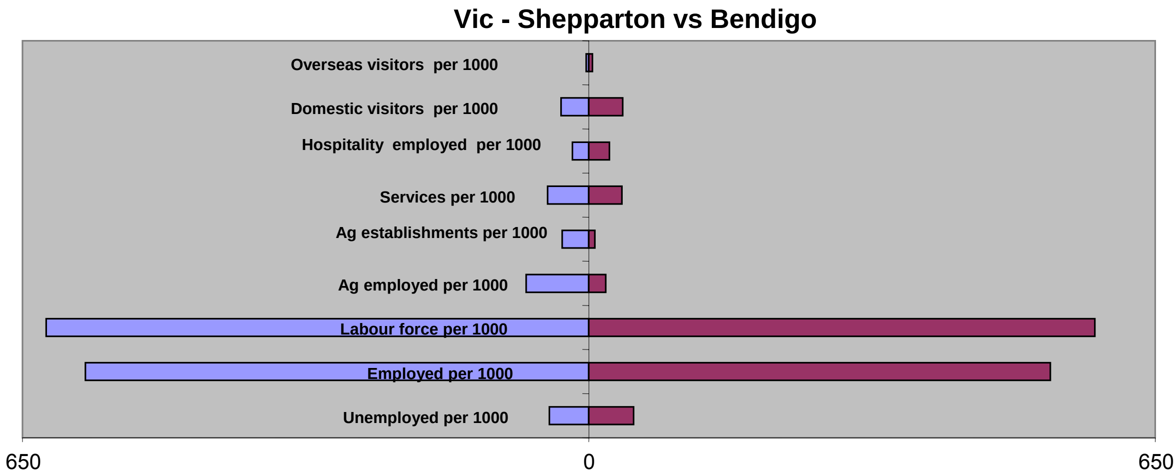


Figure 19 – Level of measured activity per thousand head of population ("intensity of activity") in an irrigated district (Shepparton) and a near by rain fed district (Bendigo) in Victoria. (Irrigated district in blue, rain fed district in purple.)

4.4 Farm gate revenue and estimated profit from irrigation

The estimated revenue generated by irrigated production rose by 50% between 1997 and 2001 to $3.1 billion (Table 17). The major contributors were dairy, with a 64% increase; grapes, with a doubling of revenue; fruit, rice and vegetables. Increased revenue is due to the increased area growing these commodities and reasonably buoyant commodity prices during this period. The distribution of revenue from the regions is shown in Figure 20. The associated revenue from rain fed production for the chosen regions (as outlined in the location map Figure 2) was $2.2 billion. Irrigated and rain fed revenue combined represented 39% of that estimated by Bryan and Marvanek (2004) in the same period for the whole of the Murray Darling Basin.

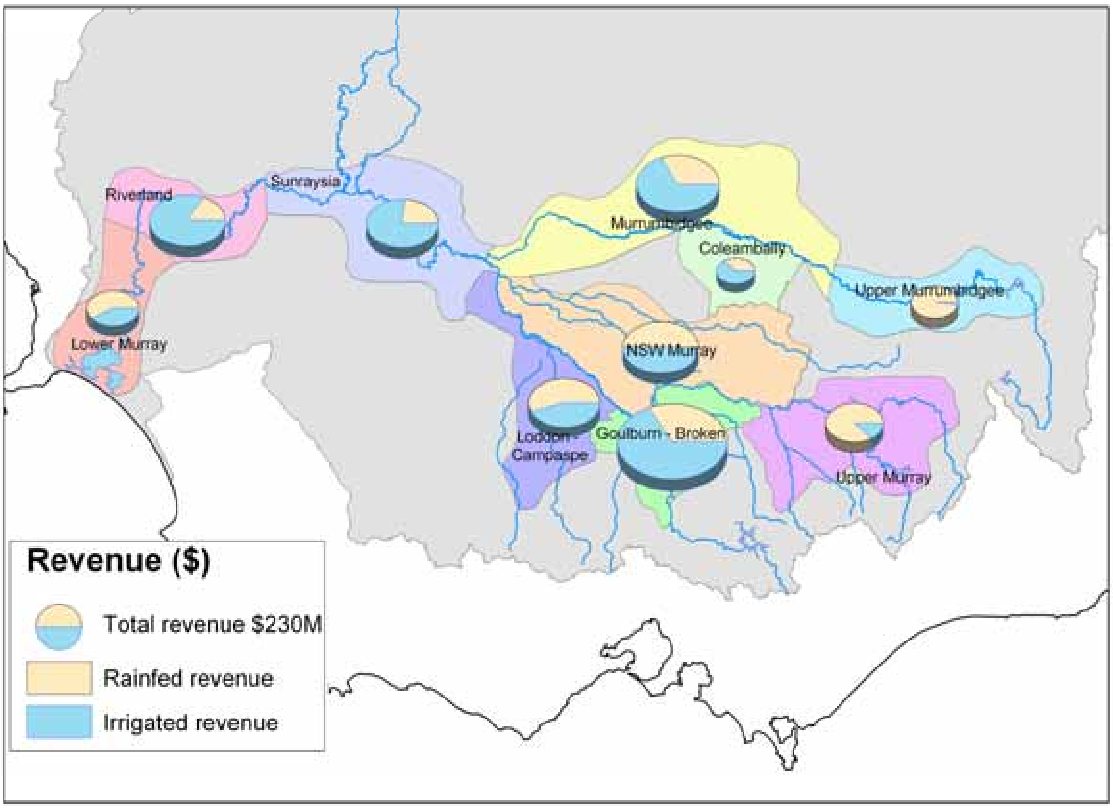


Figure 20 – Distribution of estimated revenue from irrigated and rain fed production for 2000/01.

Figure 21 ranks the farm gate revenue return per megalitre of water from the various land uses. The estimate of water used is derived from the irrigation requirement assuming that the crop or pasture is fully irrigated. As indicated in section 3.2, there appear to be considerable areas of pasture that are less than fully irrigated. Thus, the values for extensive pasture land uses (beef, sheep and dairy), are likely to be underestimates of their revenue return per megalitre. However, even if the pasture areas for beef and sheep received only half of the fully watered requirement, the return per megalitre is still low relative to other irrigated land uses. Care is needed in interpreting the return per megalitre for particular commodities. In rice farming systems for example, the amount of irrigation water applied is generally attributed to that used to produce a rice crop but a portion of that irrigation water (perhaps 1.2 megalitre per hectare) can be stored in the soil and used by a following grain crop. Ideally the return per megalitre of water should be computed on a farming system basis although this is quite difficult because of the numerous combinations that make up different enterprise systems.

Revenue per megalitre of water differs by more than one hundred fold between pastures used for beef production and vegetable production. This result can be interpreted at a national level as a signal to encourage more water to be used for vegetable production – and indeed, from the macro economic perspective generating more revenue from the use of a limited resource is advantageous. Why then, is every irrigator not trying to move into concentrated vegetable production? Apart from the immediately obvious - that vegetable markets would soon be oversupplied, there are more individual and sensible reasons why this does not happen.

From an individual enterprise perspective, generating more revenue is not necessarily the most successful business or lifestyle choice. Generally, the measure of success for these irrigation enterprises will be much more strongly influenced by the level of profit (which is not necessarily related to total revenue per megalitre), a sense of sustainability and security, the level of skill and risk involved in the production process and conscious decisions on lifestyle and production preferences. This lack of a strictly parallel relationship between return per unit of water and profit is illustrated by comparing Figure 21 and Figure 22. Figure 22 was compiled using the data and methods of Bryan and Marvanek (2004) for our irrigated regions. It shows that while rice and dairy have low revenue returns per unit of water, the estimated profit at full equity generated is very significant.

While this analysis does not give a direct breakdown at the individual irrigated enterprise level, it serves to illustrate why the aspirations and business choices of irrigators don't necessary align with resource managers in governments that use total revenue generated from resource use as a comparative yardstick i.e. there is not direct alignment of the motivators and drivers for change.

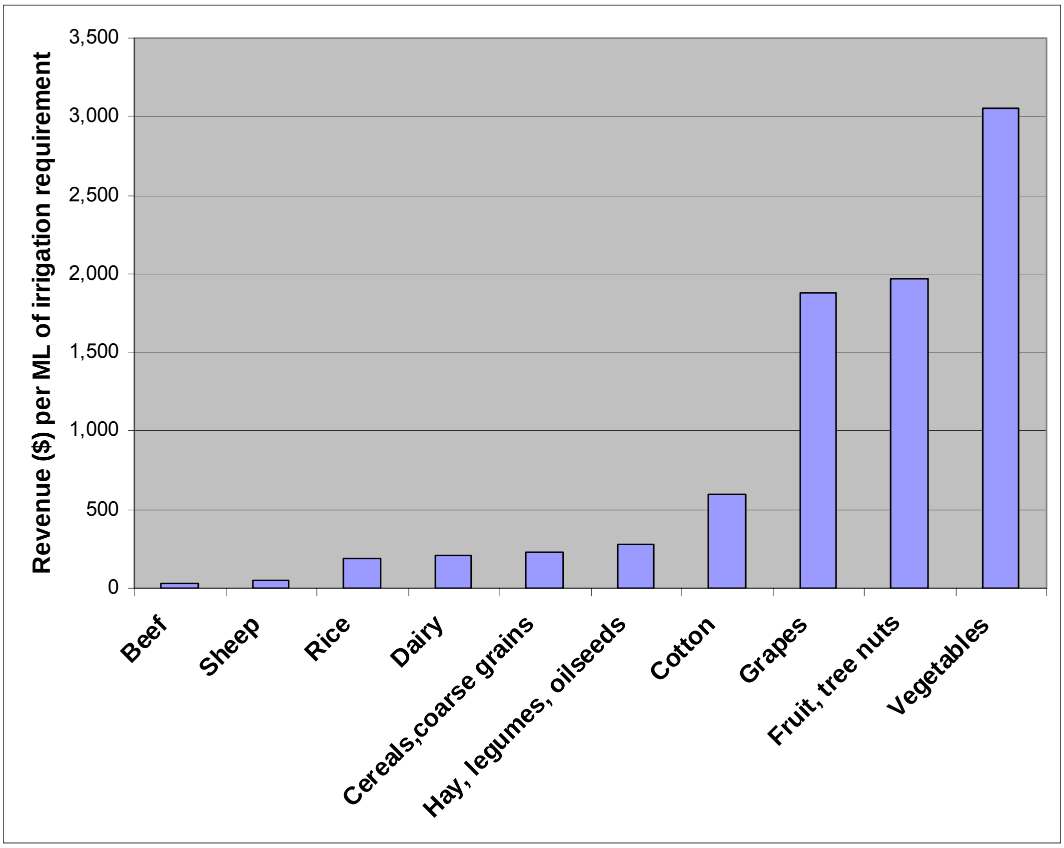


Figure 21 - Revenue generated from each land use and volume of water used.

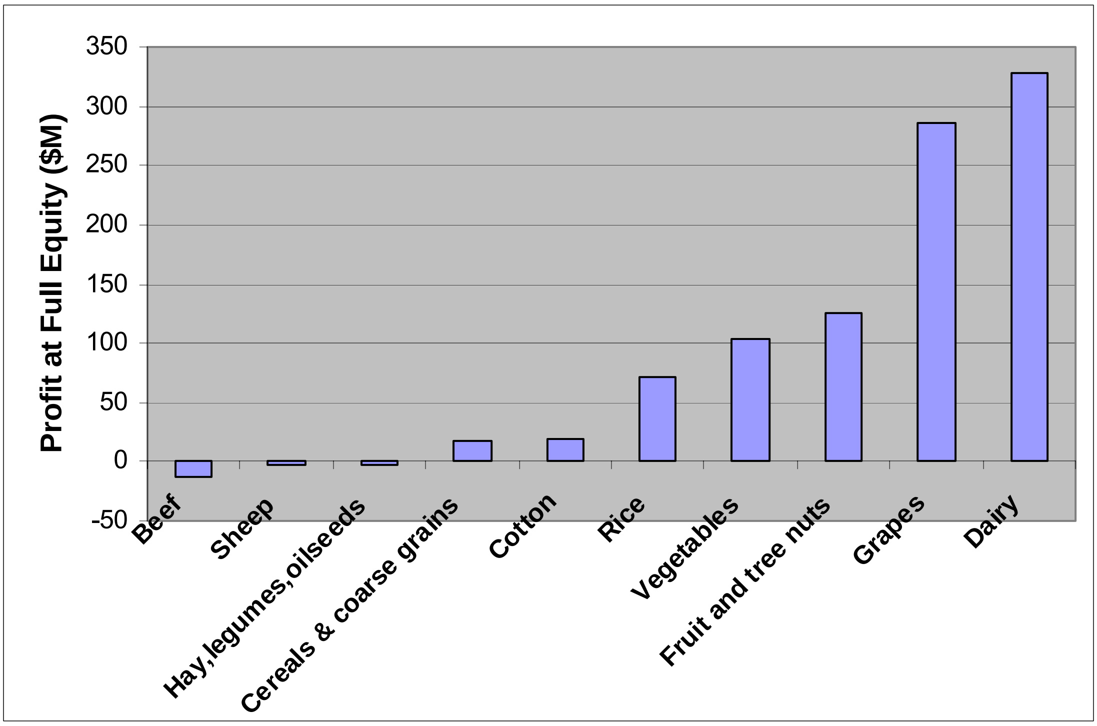


Figure 22 - Total profit from the irrigated regions by commodity for 2000/2001.

Agricultural Land Use	Irrigation Revenue ($000)	Upper Murrumbidgee	Murrumbidgee	Coleambally	Upper Murray	NSW Murray	Goulburn – Broken	Loddon – Campaspe	Sunraysia	Riverland SA	Lower Murray SA	All Regions
Beef	1996/97	242	2,529	340	492	4,783	5,886	2,987	3	6	134	17,401
	2000/01	622	5,746	587	1,458	3,694	4,531	2,401	32	7	713	19,791
	% Change	157.4	127.2	72.8	196.6	-22.8	-23.0	-19.6	909.6	23.1	432.2	13.7
Cereals & coarse grains	1996/97	0	40,476	11,242	0	8,070	2,070	6,336	126	0	32	68,353
	2000/01	102	47,244	28,723	53	32,297	5,140	10,918	180	28	255	124,939
	% Change	-	16.7	155.5	-	300.2	148.3	72.3	42.2	-	694.0	82.8
Cotton	1996/97		994									994
	2000/01		52,269									52,269
	% Change		5,158.7									5,158.7
Dairy	1996/97	0	51	0	0	16,060	392,573	104,422	0	6	4,920	518,031
	2000/01	671	2,199	141	3,521	79,027	586,655	175,307	228	248	6,315	854,312
	% Change	-	4,251.0	-	-	392.1	49.4	67.9	-	3,856	28.3	64.9
Fruit and tree nuts	1996/97	1,173	72,709	0	4,224	1,100	169,425	782	66,167	117,636	4,986	438,203
	2000/01	2,895	73,404	3,895	2,942	1,592	190,093	12,458	67,242	129,065	6,983	490,569
	% Change	146.8	1.0	-	-30.3	44.7	12.2	1,492.5	1.6	9.7	40.1	12.0
Grapes	1996/97	574	70,853	1,040	3,485	0	1,480	10,410	171,322	136,039	9,861	405,863
	2000/01	994	103,251	1,178	14,828	7,029	8,864	17,304	293,733	326,228	70,878	844,284
	% Change	73.2	45.7	13.3	325.5	-	499.1	66.2	71.5	139.8	618.8	108.4
Hay, legumes, oilseeds	1996/97	0	9,346	5,003	12,993	8,379	29,035	10,894	470	25	2,206	78,352
	2000/01	85	10,673	1,760	22,770	3,814	3,675	4,159	2,749	31	3,985	53,700
	% Change	-	14.2	-64.8	75.2	-54.5	-87.3	-61.8	484.5	20.8	80.6	-31.5
Rice	1996/97	98	114,007	52,872	666	139,691	2,217	0				309,553
	2000/01	0	129,116	52,397	366	162,903	2,587	912				348,282
	% Change	-100.0	13.3	-0.9	-45.1	16.6	16.7	-				12.5

Sheep	1996/97	170	3,234	181	1,100	6,043	3,513	8,068	18	5	230	22,563
	2000/01	0	669	43	176	705	2,440	6,584	0	0	135	10,752
	% Change	-100.0	-79.3	-76.5	-84.0	-88.3	-30.5	-18.4	-100.0	-100.0	-41.1	-52.3
Vegetables	1996/97	1,894	40,561	7,236	1,097	13,332	28,170	7,189	46,668	26,762	34,313	207,222
	2000/01	126	72,519	7,683	0	17,579	67,506	17,656	58,711	59,547	35,263	336,589
	% Change	-93.3	78.8	6.2	-100.0	31.9	139.6	145.6	25.8	122.5	2.8	62.4
All Land Uses	1996/97	4,151	354,761	77,914	24,057	197,459	634,369	151,089	284,775	280,479	56,681	2,065,735
	2000/01	5,495	497,089	96,406	46,113	308,640	871,491	247,699	422,875	515,153	124,527	3,135,488
	% Change	32.4	40.1	23.7	91.7	56.3	37.4	63.9	48.5	83.7	119.7	51.8

Table 17 – Estimated revenue ($ thousands) by irrigated land use and region for 1996/97 and 2000/01.

4.5 Variability of irrigated productivity at enterprise level

As with any business activity, the performance of an irrigated enterprise depends on the use of resources, the uncertainties of weather and markets and the management skill of the people involved. It is hardly surprising then that different outputs come from different irrigated farms with apparently similar resource inputs and market opportunities. A key study that demonstrated this was done by Skewes and Meissner (1997a, 1997b) for citrus and wine grapes in the Riverland and Sunraysia regions. They collated the production, water use and financial data for nearly forty "good" irrigators of citrus and similarly for wine grapes.

Examples of the results for citrus are shown in the following Figures (Figure 23, 24, 25, and 26) with five of the higher performing farms highlighted in each of the metrics. Very similar trends were evident in the wine grape farms.

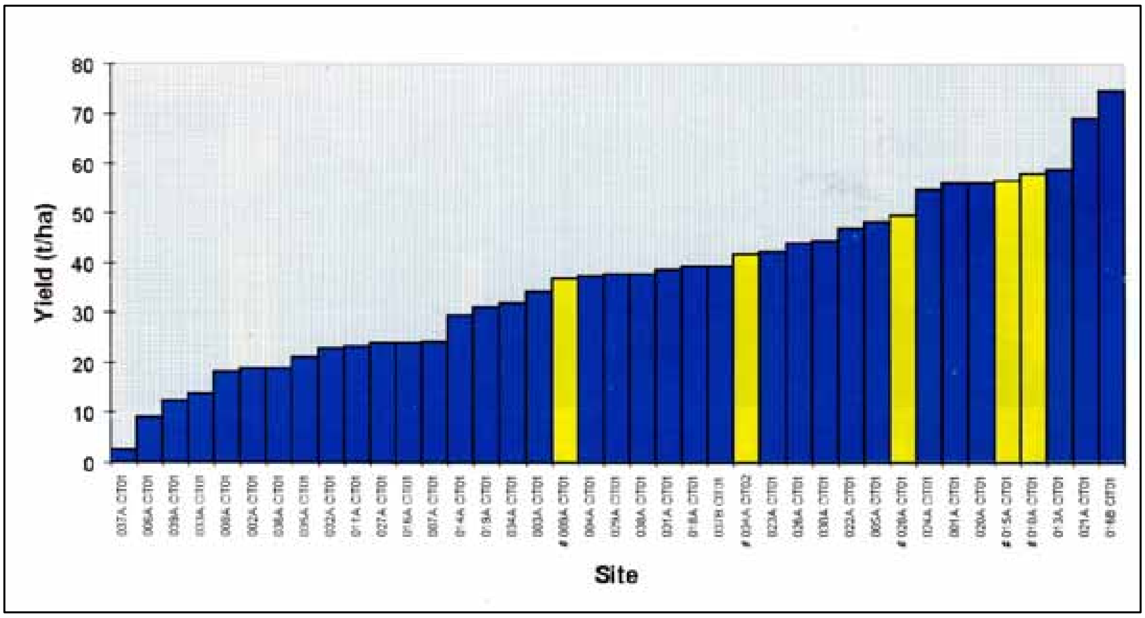


Figure 23 – Yield of citrus (t/ha) from 39 irrigated farms (Sites) in the Riverland and Sunraysia. Five farms are highlighted to assist tracking them through the other figures below. Data from Skewes and Meissner (1997a).

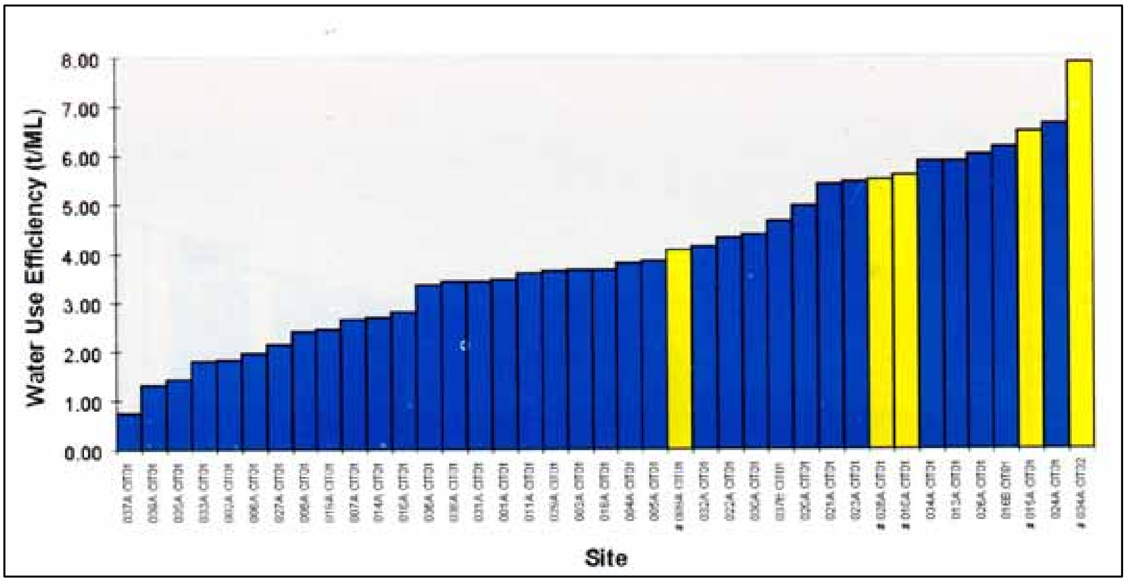


Figure 24 – Water productivity ("Water Use Efficiency") on 39 different citrus farms

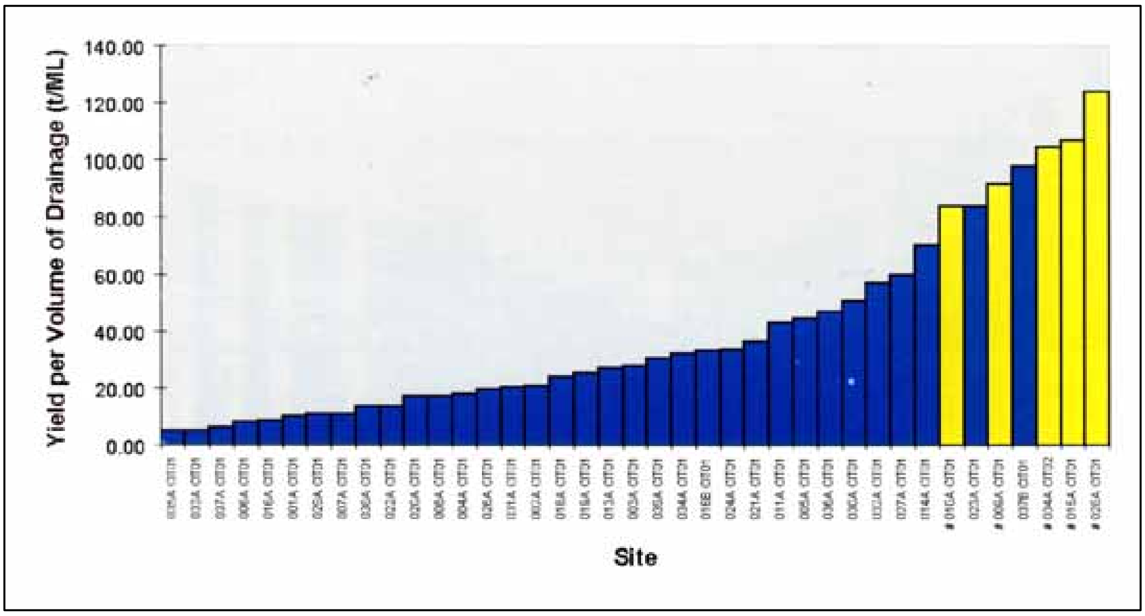


Figure 25 – Yield (t) of citrus per unit of drainage (ML) on 39 different farms

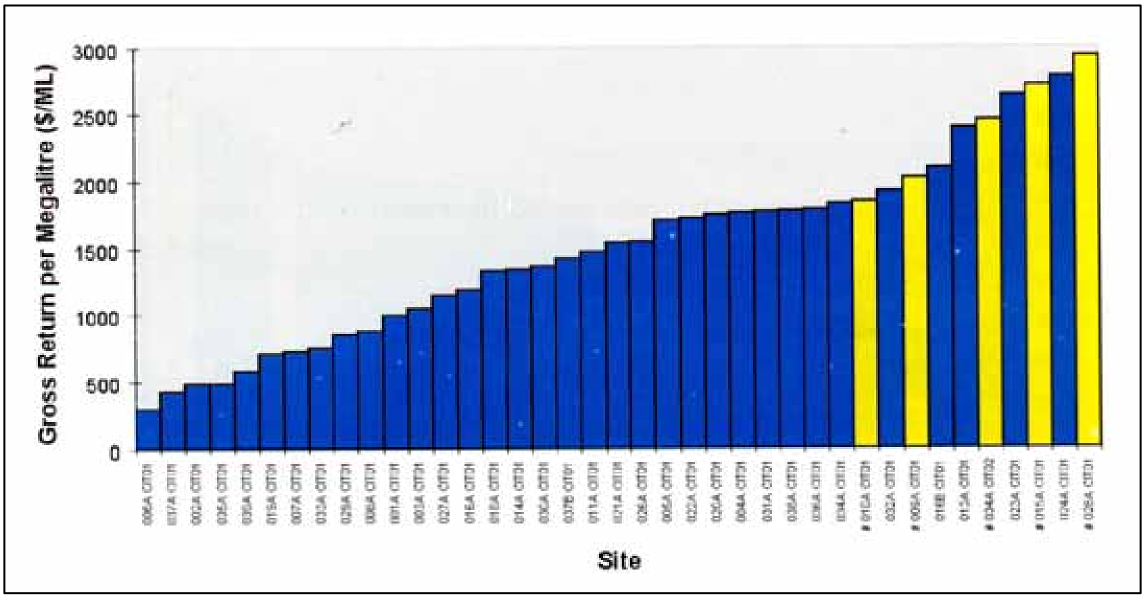


Figure 26 - Gross return ($) per unit of irrigation input (ML) on 39 different citrus farms

The Skewes and Meissner data illustrate very nicely what most industry commentators intuitively suspect ie there is a surprisingly large range of outcomes from seemingly similar irrigated enterprises. For example, land productivity (yield per unit area) varies from less than 5 t/ha to more than 70 t/ha. Irrigation water use and productivity varies widely so that water productivity (yield per unit of water) varies from less than 1 t/ML to more than 7 t/ML, while associated drainage from the farm also varies widely. Farms at the upper end of performance with respect to resource use and productivity also tend to be those at the high end of the gross return per unit of water. Without accompanying data on profit from these enterprises, it is difficult to comment on the viability of the farms and the relationship to resource use. However we can be quite confident that profitability will have a reasonable relationship to gross margin and it will also show a variation that is comparable with all the other measures taken.

Given that the data in the Skewes and Meissner surveys were collated from “good” irrigators, it is reasonable to assume that the variation in performance of irrigated enterprises is much, much larger across the same commodity production system. There will be a host of reasons for the variable performance of irrigated enterprises and there is little doubt that significant improvement is possible in even the better performers, let alone those at the lower end of the benchmark tables. It is this kind of data and the knowledge of what is possible from regional research that encourages State extension agencies and private consultants to develop best practice guidelines for irrigated production. Clearly, improved land and water productivity is possible – identifying the mix of information, incentives and market signals to achieve improved productivity is the challenge.

4.6 Value adding associated with irrigated activity

Associated with any level of primary production is accompanying and interdependent economic activity that provides support through provision of goods and services. In addition, there is the economic activity associated with processing and distribution, for example cheese making from dairy milk production or wine making from grapes. This activity is generally referred to as the “value add”, although most people when using this term are thinking about the “downstream” activities of processing and distribution. Contemporary analysis also recognises the “value add” associated with the supply of goods and services for the primary production to occur.

In this study we consider the irrigated production at the farm gate as our point of reference (e.g. milk production from an irrigated dairy) with the supply of goods and services to enable the dairy to produce milk called “upstream” value add and dairy processing (fresh milk and dairy products) as “downstream” value add.

Identifying the size of the value add is very demanding because of the need to untangle the inter connections between many of the activities. This was initially done at a national level but regional estimates have recently become available and are used with input/output modelling systems. We have accessed sets of multipliers developed for the Goulburn Broken region and for the Murrumbidgee region.

The multipliers (Table 18) are generally applied as economic activity multipliers for commodity or primary production categories or - in the case of the Goulburn region - as job multipliers dependent on the primary production jobs. In applying the multipliers we have been careful to consider only those categories where there is a high chance that all of the production is irrigation related. We have also used the most generous interpretation of the activity generated by primary production because we have used “type 2” multipliers that consider the direct, indirect and induced effects of irrigated farm gate revenue.

Region	**Industry Sector**	**Economic Multiplier**	**Employment Multiplier**
Murrumbidgee*	Beef Cattle	1.3	na
	Citrus	1.3	na
	Food Manufacturing	1.9	na
	Forestry/Fishing	1.3	na
	Fruit/Veg Processing	1.6	na
	Grapes	1.5	na
	Horticulture	1.4	na
	Meat Processing	1.8	na
	Mining	1.4	na
	Rice	1.5	na
	Rice Milling	1.7	na

Region	Industry Sector	Economic Multiplier	Employment Multiplier
	Sheep Meat	1.7	na
	Tourism/Recreation	1.3	na
	Transport/Communic.	1.2	na
	Vegetables	1.5	na
	Wine Production	1.6	na
	Wood/Paper Products	1.5	na
Goulburn-Broken*	Cereal Crops	1.6	1.5
	Community Services	1.2	1.2
	Dairy	1.6	1.9
	Dairy Processing	2.4	4.0
	Forest Softwood	1.7	2.6
	Fruit	1.7	1.7
	Fruit Processing	1.7	2.8
	Grapes	1.6	1.2
	Grazing	1.6	2.4
	Hay/Seed	1.7	1.5
	Meat Processing	2.1	2.1
	Mining	1.6	1.6
	Other Horticulture	1.6	1.2
	Other Manuf	1.5	2.7
	Tomatoes (Proc)	1.7	1.2
	Tourism	1.4	1.1
	Transport & Communications	1.2	1.6
	Veg Processing	1.9	3.7
	Wine	1.7	3.3
	Wood & Paper Manuf	2.3	3.4
SA-Murraylands*	Sheep	1.4	1.4
	Grains	1.6	1.2
	Beef	1.5	1.3
	Dairy	1.6	1.6
	Wine grapes	1.5	1.4
	Vegetables	1.5	1.8
	Fruit & Nuts	1.5	1.5
	Service Agriculture	2.0	2.2
	Food Products	2.0	3.5
	Wine & Beverage	1.9	4.1
	Wood Paper	1.5	1.7
	Machinery Equipment	1.4	1.7
	Electricity Gas	1.7	2.6
	Water	1.4	1.7

* Input / Output multipliers for Murrumbidgee were kindly supplied by Dr John Tisdell (Pers. Comm. 2005), for Goulburn Broken from Dr Roel Plant (Plant et al 2003) and for SA from an Econsearch report to the Department of Trade and Economic Development.

Table 18 - Input/Output economic and employment multipliers from Murrumbidgee and Goulburn for selected irrigated activity related categories. (na = not available)

It is immediately evident from Table 18 that the multipliers developed for the different regions, for apparently similar production categories, are not the same. This is not unexpected given that survey methods are used to derive the multipliers. Some of the differences will be real since different cost structures and processing opportunities occur in the regions.

Using the Goulburn multipliers as an example, we see that the “upstream” activity associated with dairy has an economic multiplier of 1.61, for grapes the multiplier is 1.56. This means that for every $100 generated as revenue by dairy or viticulture, there is an accompanying and supporting economic activity of an additional $61 for dairy and $56 for grape production. The employment multiplier indicates that for each job in dairy there are an additional 0.89 jobs generated to support dairy while in grape production an additional 0.22 jobs are generated. If we now look at the “downstream” effect, dairy processing has an economic multiplier of 2.42 and wine, 1.69. For employment, dairy processing generates an additional three jobs (ie a multiplier of 4.00) while wine generates an additional 2.30 jobs. In Table 19, the “upstream” economic multipliers have been applied to the total revenue figures for the ten irrigated commodity classes used in this study to give aggregated value add. We have also applied the “downstream” multipliers for only four categories (dairy processing, fruit processing, vegetable processing and wine) because almost all primary production associated with these will come from irrigation.

The total multiplier associated with irrigated production will be the sum of the “upstream” and “downstream” economic activity estimates. For example, using the four categories identified above (dairy / dairy processing, fruit / fruit processing, vegetables /vegetable processing, grapes / wine), the average upstream multiplier is 1.6 while the average downstream multiplier is 1.9. From this it is reasonable to indicate that these irrigated activities generate a level of economic activity that is 3.5 times the farm gate revenue.

While it is generally true that irrigated activity and its associated value add effects tend to have reasonably high multipliers in terms of both economic activity and job increases, there is some rainfed production that has equivalent effects. For example, grazing has an economic multiplier of 1.65 and a job multiplier of 2.37. The “downstream” effect through meat processing has multipliers of 2.06 and 2.10 for the economy and jobs respectively. Similarly, wood and paper manufacturing has multipliers of 2.29 and 3.42. In this latter case, forestry may become a serious competitor for irrigation water if more area in the higher rainfall catchments is planted to forests and runoff is reduced.

Table 19 shows the variations of value add across different irrigated commodities and also the aggregated total across all commodities and, therefore, regions. Using the Goulburn Broken “multipliers” (Table 18), we calculate that from the estimated revenue of $3.1 billion, an additional $1.86 billion (from the total of $4.96 billion) is generated in support goods and service activity. For the four selected “downstream” processes the revenue base increases with value add by an additional $2.46 billion. If we nominally apply the multipliers across our ten commodity groups and consider all regions then the estimated “downstream” value is $7.8 billion, an increase of $4.7 billion associated with processing and distribution.

Primary industry	Values in $'000s		
Land Use	**Revenue**	**Goulburn Broken value add**	**Murrumbidgee value add**
Beef	19,129	31,562	25,250
Cereals & coarse grains	124,939	201,715	179,912
Cotton	52,269	81,419	75,268
Dairy	853,720	1,375,232	1,126,910
Fruit and tree nuts	490,569	815,932	613,211
Grapes	832,988	1,300,989	1,274,472
Hay, legumes, oilseeds	31,167	51,640	37,712
Rice	348,282	562,305	515,457
Sheep	10,752	17,740	18,063
Vegetables	336,589	524,305	508,250
All Land Uses	3,100,404	4,962,839	4,374,506
Selected "downstream" processes			
Dairy processing	853,720	2,064,132	na
Fruit processing	490,569	851,498	789,816
Wine	832,988	1,407,180	1,299,462
Vegetable processing	336,589	651,020	541,909
Total for "downstream"	2,513,867	4,973,830	na

Table 19 - Total “upstream” and “downstream” value add associated with irrigated commodity production, its processing and distribution.

4.7 Trends

The primary determinant of irrigation - water availability - is currently of intense interest. Clearly, the dry years of 2001/02 have focussed attention on the finite limits to the volume of water that can be stored and then subsequently allocated for different uses. The Murray-Darling Basin Commission “Cap”, and now action through the “Living Murray” process to assign greater water volumes for river and riverine environmental purposes, means that the available surface water resources for irrigation will be static at best but, more realistically, reduced from their previous levels.

On the basis of the diversions for 2001/02, 500 GL less is a 5.8% reduction while a proposed value of 1,500 GL would be a 17.4% reduction. The limited data currently available tends to confirm that increased groundwater use is partially offsetting declining surface water availability. The extent of this will be regionally specific because suitable and exploitable groundwater reserves are variable through the regions but the trend will continue as will the need to monitor and manage this resource.

The flexible or “plastic” nature of the area that can be irrigated is well demonstrated by the responses in the regions over the last eight years. The imposition of the “Cap” focused people’s attention on the reality that the amount of available water was finite within any year and that there was now greatly increased competition for this water. The predictable human response to this realisation was a rapid increased valuation of the water resource expressed in improved distribution effectiveness, increased cost of tradeable water and greater and more concentrated use on farm.

Hence, from 1996 to 2001, the area of irrigated dairy pasture increased, as did the area of high value crops such as grapes, fruit and vegetables. The onset of the dry period, and an unprecedented low amount of diversion, have caused a major decrease in the area of irrigated pasture, while the high value crop area has continued to increase – an expansion that is facilitated by both permanent and temporary water trading. It is expected that the trends demonstrated here will continue ie the irrigated pasture area will be quite "elastic" as water availability and commodity prices fluctuate, with a long term trend of decreasing area, while high value crop area will grow at a rate largely determined by relative commodity prices.

At the highest level of aggregation, the revenue from irrigated activity has a 32% return on the asset value of the water delivery and application infrastructure. If the nominal asset value of water is added, the return decreases to 18%. More realistically, if the associated on farm production assets (machinery, fencing, buildings, dairies) are included then the return decreases to about 8%. While this appears to be a fairly modest return on total replacement value equity it is almost certainly a better return than from rain fed agriculture. As indicated in the report by Bryan and Marvanek (2004), the estimated profit at full equity generated from irrigated agriculture is an order of magnitude and up to twenty times higher on a unit area basis compared with that from rain fed agriculture.

Comparisons between the regions need to be treated with great care because there is always considerable diversity within a region and it is often hard to obtain data that is directly comparable for a land use or enterprise. We have chosen to present a comparison at the most aggregated level ie to use the total irrigation related revenue estimate and the total water diversion attributed to the region. Figure 27 shows the revenue per unit of water diverted for irrigation together with revenue relative to the total water input that includes rainfall. What this data clearly shows is the large return from the Riverland and Sunraysia regions relative to the eastern, more extensive irrigated production. To illustrate this difference:

NSW Murray region irrigates 321,000 ha with a diversion volume of more than 2,000 GL to produce irrigated revenue of about $310 million. The Riverland region irrigates 36,000 ha with a diverted volume of 311 GL to produce irrigated revenue of $555 million ie one tenth of the area with one sixth of the water producing 1.8 times the revenue – clearly a much more intensive irrigated system.

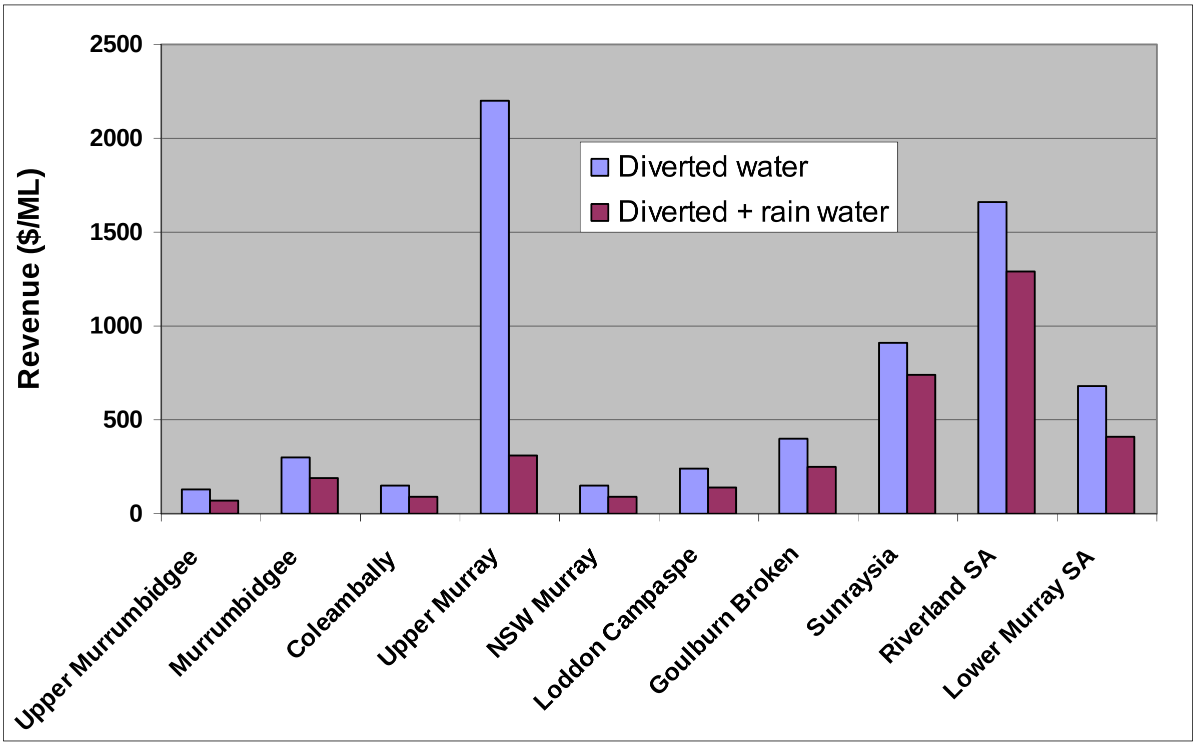


Figure 27 – Comparison of revenue/ML generated from the total diverted water volumes and the total water input (diverted irrigation volume plus rainfall).

Recognising that water input is critical to productivity, it is possible to compare the revenue return associated with the rain input of the rain fed districts with the revenue return from the irrigation water and rain in the irrigated districts. The average annual rain input to each of our three district pairs was calculated and, in the case of the irrigated districts, the average irrigation amount was also added.

Aggregating across the three district pairs, one from each State, shows that the total water input from irrigation above rainfall was 2.4 times greater (4.47 Ml/ha rain-fed, 10.93 Ml/ha rain plus irrigation), with a revenue generation that is 13.1 times greater ($52.45/Ml rain-fed, $686.83/Ml rain plus irrigation). This increased revenue supports the observed level of economic activity that is about four times greater than in the adjacent rain-fed district.

Although quality data are limited, there is some evidence, supported by regional observation, that the area of controlled irrigation systems, primarily associated with vine and tree crops, is increasing - both for existing and for new plantings. It is highly likely that micro irrigation systems will continue to be installed and a doubling of the current area (132,000 ha) is certainly feasible over the next decade. This will occur both in existing irrigated areas and in new irrigation developments. There is some replacement of surface irrigation with large moving sprinkler systems for vegetable and intensive fodder and grazing but this is likely to remain a small proportion of the total irrigated area.

Apart from the obvious drainage needs in the most acutely affected areas, the need for sub surface drainage is still grossly under-valued. The majority of irrigated areas continues to use unsaturated sub surface layers to receive drainage waters. This will delay the time that sub surface drainage is needed for water table and salinity control. However, with current irrigation practice, especially while surface irrigation predominates, there will continue to be net additions to most groundwaters. New drainage design criteria are needed that provide adequate protection for crops (with clear delineation of waterlogging and salinity control objectives) whilst minimising drain water salinity and volume. The fate of the saline drainage water is a key issue across all regions and, without proper and extensive research and planning, the antipathy towards salt storage basins may severely restrict future use of subsurface drainage in irrigated agriculture. No region has a fully detailed plan and costing of the subsurface drainage required to protect all areas with potential or existing drainage problems.

With improvements being made to the processes of water trade there is little doubt that water will continue to move to enterprises where they can make a credible business case for profit, viability and market duration. The transfer of water in this market setting occurs because there is a willing buyer and willing seller. Both parties will have satisfied themselves that the deal is in their best interests and, for the buyer, there is a perception and belief that this will be advantageous for their enterprise.

While this transfer is generally going to be beneficial for the national interest (of returning more profit from the use of resources), this result is not well linked to the productivity of other downstream enterprises and the public interest. It follows then that a sole focus of government policy towards increased “water use efficiency” (generally measured in terms of $’s/ML) will not necessarily achieve the right balance of private investment and public interest in responsible resource management. It will be important to use more than $’s/ML as indicators of improved triple bottom line performance.

Such balance is more likely to be achieved with a mix of market signals that help set the value of the resource (mostly water, in this case) and clear “rules of engagement and operation” that define the planning and operating criteria to protect public and long term interest in the use and maintenance of the resource.

The building awareness of water in Australia and the impact of the dry period in the last three years have precipitated a social and political environment from which major shifts and changes can be expected. It is likely that we will see increased diversification of enterprises, a greater adoption of technology and decision aids, and a general improvement in productivity. This augurs well for Australian irrigation and its productivity.

5 Effect of irrigation practice on water and land resources

In a paper at the 1993 symposium, "The Future of Irrigation in the Murray Darling Basin", Meyer and Noble (1993) summarised the impact of irrigation on resources as follows.

"Irrigation development has changed the appearance of large tracts of land in the Murray-Darling Basin. A large infrastructure investment has brought productive agriculture and community growth to semi arid, inland Australia. On the land, native vegetation has been removed, wetlands drained or flooded, earth moved and drainage lines changed and soils cultivated. The extensive clearing and subsequent addition of large volumes of water has caused a fundamental change in groundwater distribution. In the rivers, flow patterns and volumes are very different with return of drainage waters contributing nutrients and chemicals.

"There are clear signs that not all of these changes have a net benefit. The maintenance of the basic resources, soil and water, is presently inadequate and unbalanced. Changes in management which bring about reduced drainage and containment of salt are needed. However, current profitability of many enterprises is low, and unless productivity can be markedly improved it will be extremely difficult for irrigators to make changes. Facilitating the move of water from lower to higher productivity areas and commodities will help, as will continued improvements in delivery and drainage systems. Setting clear guidelines which indicate desirable goals, will provide direction and a measure of progress for community land and water management planners."

The essence of this description remains as relevant today, ten years later, as it did at the time. A paper by Bowmer (1993) presented at the same symposium as that referred to above, provides an excellent summary of the “environmental impacts of irrigation on the Riverine aquatic environment and water quality downstream”. The next sub-sections deal with these major impacts of irrigation while the following section (6) brings together activity that is aimed at achieving a balance between production and effective resource use.

5.1 Effect on the supplying rivers, wetlands, floodplains and riverine vegetation, biodiversity

The total diversion of water for irrigation from the Murray and Murrumbidgee is substantial as shown in Section 3.3 and illustrated in Figure 28. The audit process of water diversions from the Murray and Murrumbidgee, begun in 1994, showed that more than 90% was diverted for irrigation and stock and domestic purposes (Murray-Darling Basin Commission 1995). Clearly, this level of diversion has a very large effect on both the seasonality and duration of flows. This is best illustrated in Figure 29 from Close (1990) that shows current median flow patterns relative to estimated pre-development flows. Apart from a reduced frequency of high flows, the timing of high flows has been altered to meet the requirements of the irrigation industry. Essentially, major flows in the upper River reaches now peak in summer associated with "irrigation flows" compared with spring peaks under pre-development conditions, and the frequency of small to medium floods has decreased from eight years in ten to less than four years in ten.

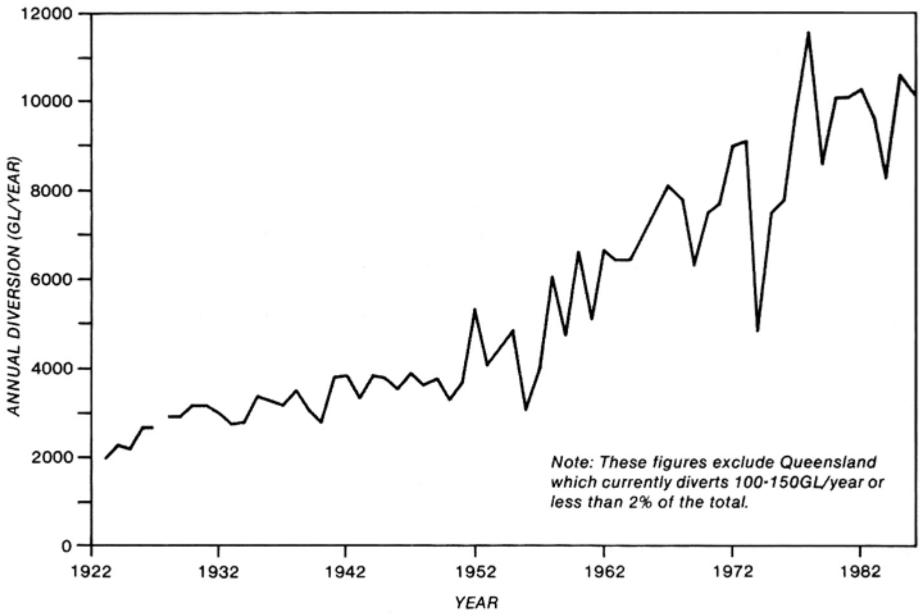


Figure 28 – Annual diversions in the Murray- Darling Basin. Reproduced from Figure 4.1 in Close (1990).

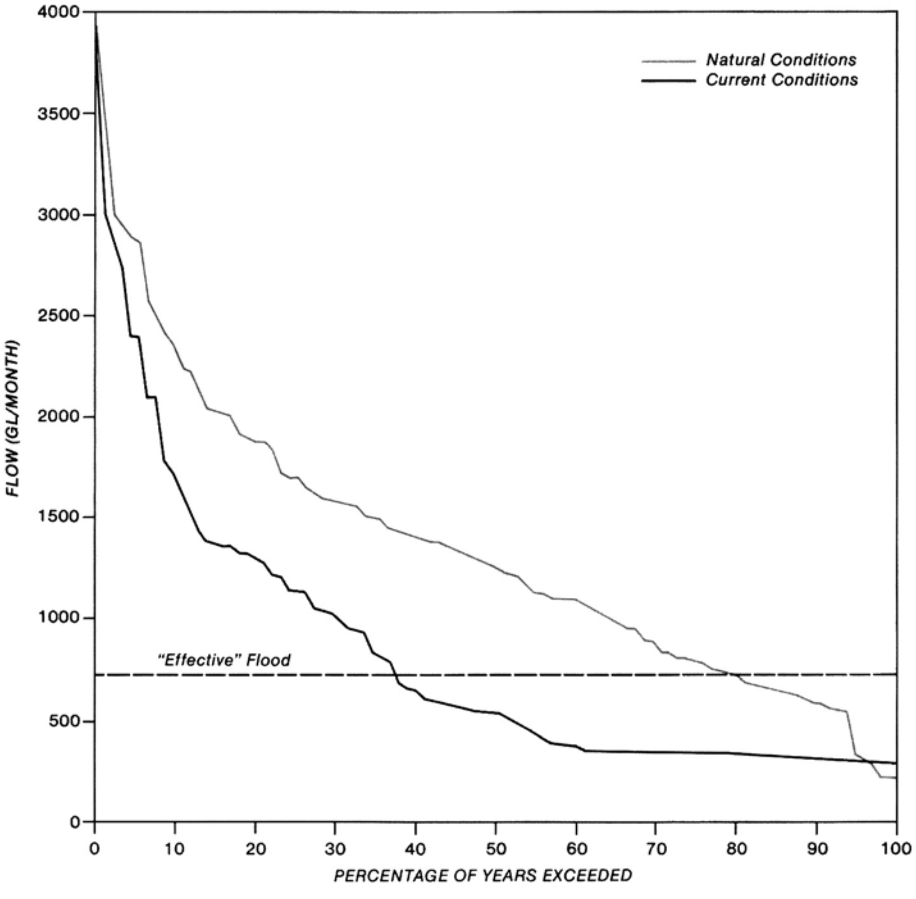


Figure 29 – Peak monthly flow in each year – "natural" vs. "current" at Yarrawonga. Reproduced from Figure 4.6 in Close (1990).

The consequences of markedly changed flow regimes on the river and riverine environments have been profound, even though the full impacts are still developing and, more importantly, still being documented. The invasion of carp in the rivers is almost certainly an expression of an altered environment that favoured its breeding and feeding habits relative to that of native species (Schiller and Harris, 2001). The flooding of large, near river areas and "drowning" of red gums when weir pool levels rose with the installation of the Locks in the Lower Murray, is still evident. The current deterioration of floodplain vegetation in the Sunraysia, Riverland and Lower Murray regions is mostly attributed to limited flooding and consequent accumulation of discharging saline groundwater (Overton and Jolly, 2004). This situation has been exacerbated by the extended dry period since 2000/2001 while the effect of persistent grazing of these riverine areas is probably under estimated.

Until recently (within the last twenty years), management of the major catchment storages was primarily for provision of irrigation water. As the demand for electricity increased, so did the emphasis on optimising water release to generate high value power. This has coincided with an increasing recognition of the recreation value from storages and river flows and, in the last decade, the need for in-stream and riverine management.

This has made managing storages and "running the rivers" even more complex. For example, developing the flow guidelines for the Murrumbidgee (NSW DSNR 2003) was an extremely demanding task involving extensive community engagement from diverse interest groups - all the while dealing with incomplete hydrologic, physical and economic data.

5.2 Effect on groundwater

As indicated in section 3.8 (Drainage infrastructure and salt management), the connection between the surface applied water for irrigation and underlying groundwater largely determines the water and salt balance sustainability of irrigated areas. It is only in the last twenty years or so that there has been sufficient information available to present generalised representations of the hydro-geology of the Murray and Murrumbidgee Basins (see Evans et al. 1990, Ife and Skelt 2004). With this increased understanding has come the realisation that all land use systems (rain fed and irrigated) that change the basic vegetation and green leaf cover and duration effect recharge to the groundwater. Hence, the change, through clearing, from essentially ever-green native vegetation to largely annual pastures in the south eastern Goulburn catchment areas of Victoria has mobilised the large regional aquifer (deep-lead) systems. These effects are then expressed as increases in the groundwater pressures in the deeper aquifers, often 70 to 100 m below surface and often hundreds of kilometres from the major recharge source. In the Goulburn and Loddon regions we know that the major groundwater flow lines are towards the Murray River and in Loddon, the discharge is on the northern Loddon Plain, an area dotted with shallow saline lakes (Macumber 1990). The active saline lakes (Figure 30) scattered across the western part of the Basins are an expression of groundwater discharge from the regional aquifers.

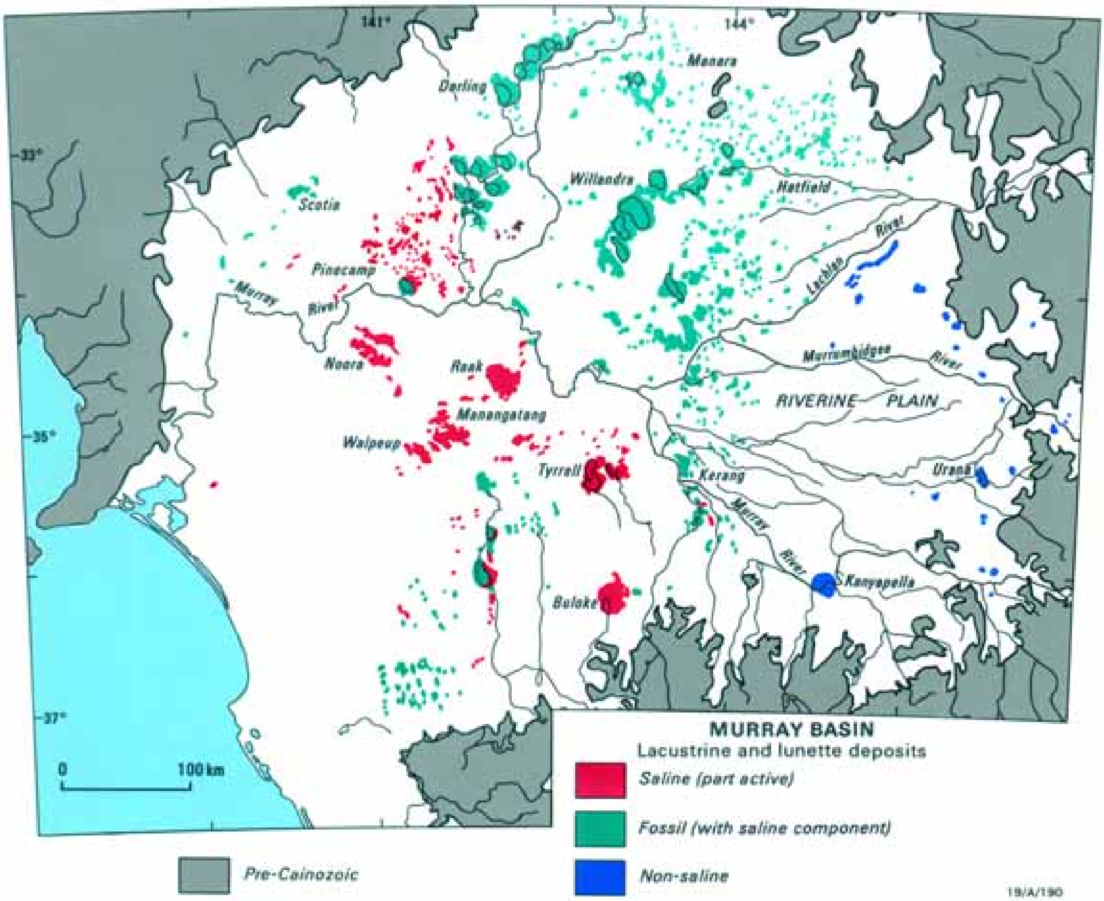


Figure 30 - Groundwater discharge lake complexes at present day surface of Murray Basin (reproduced from "The Murray")

When irrigation, with its attendant drainage to groundwater, is added on top of a groundwater system that has regionally influenced upward groundwater pressures, it is inevitable that shallow water tables, waterlogging and increasing salinity will result. Hence, the large areas of Goulburn Murray, Loddon Campaspe and the Wakool areas in NSW Murray are affected in this way. The irrigated future of these areas will be determined by the success of sub-surface drainage schemes and the ability to keep salinity in the root zone below plant susceptibility levels.

In situations where regional groundwaters are less influenced by major land use change in remote recharge areas, the development of an irrigation area will impact on the groundwater, mostly in the upper regolith layers. One of the best documented cases is the development of the unconfined groundwater mound under the Coleambally Irrigation Area in southern NSW. Irrigation in the region began in the 1950s and, within thirty years, water table levels rose from about 30 m below ground surface to within 2 m. Rates of recorded rise were between 0.5 m and 3 m per year. As the levels in the mound rise, so does lateral dissipation, although this rate is generally quite slow (1 to 10 m per year) because of the low gradients and generally fine textured soils through which the water is moving.

Water moving through these unconfined aquifers is also dissolving stored salts and, in the old landscapes of the Murray, there is considerable stored salt. Hence, eventual discharge into streams and rivers will almost certainly be with a higher salinity level than the recharge waters and the volume of discharge will be less (maybe 10%) of the recharge amount because of losses through storage and evapotranspiration along the way.

5.3 Managing salt, its movement and its storage

Due to the persistent rising salinity levels in the Murray River (Figure 31) during the decades leading up to the mid 1980's the Murray Darling Basin Commission developed the "Salinity and Drainage Strategy" in 1988 (Murray-Darling Basin Commission, 1989) to contain the salinity levels and improve water quality in the River.

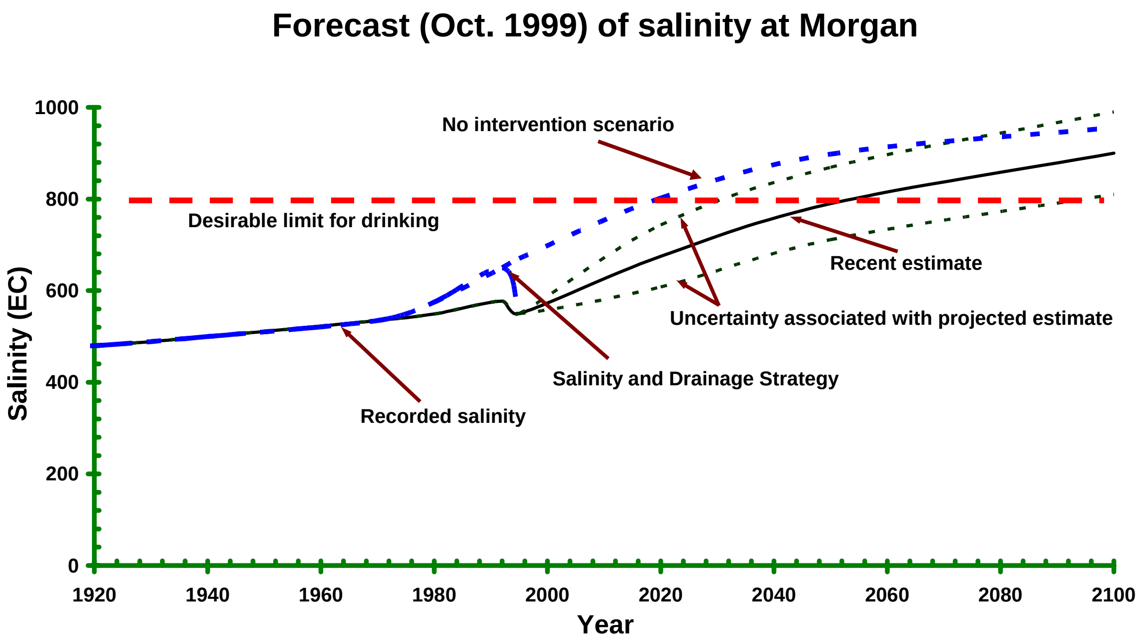


Figure 31 - Measured and predicted river salinities at Morgan on the Murray River (Murray-Darling Basin Commission, 2005) (1000EC = 1 dS/m)

The Salinity and Drainage Strategy depended on each State being responsible for any actions significantly affecting river salinity and hence being responsible for the impacts of irrigation areas on water quality. States were allocated a Salt Disposal Entitlement (SDE) and they were required to balance salinity credits and debits to ensure that salt export did not exceed the allocated SDE. Complying with these requirements has become the major limiting factor in disposal of salt mobilised by irrigation drainage.

In 2000/2001 salinity control has been given further focus by the setting of end of valley targets for individual river systems (Murray-Darling Basin Ministerial Committee, 2001). This has renewed efforts to focus on some point sources e.g. irrigation return flows and sewage works discharges, and diffuse sources such as dry land salinity in upper catchments and salt interception schemes for groundwater discharge to the Murray in South Australia.

The emphasis on keeping salt out of rivers has led to state and regional policies in irrigated areas that restrict the mobilisation of salt, strict controls on the installation of subsurface drainage, recycling on farm drainage and restricting the disposal of saline water within the irrigated area. For example, in the Murrumbidgee Irrigation Area any new subsurface drainage system must discharge to an on farm evaporation basin. It is likely that such requirements will continue to be rigorously enforced given the on-going concern about salinity levels in the Rivers.

Within the MDB the salinity and drainage strategy has been solely focused on managing the salt loading into the river (see Murray-Darling Basin Commission 2001). Evidence thus far is that salt loading in the River Murray as measured at Morgan has been effective. Salt interception schemes e.g. Barr Creek discharge, groundwater interception in the Sunraysia and Riverland can be effective but they are long term commitments.

The current activity, while apparently effective, will do little to reduce the total volume of salt in these regions – the analogy is that our efforts are the equivalent of shifting all the sand on a very large beach using a teaspoon – we can be locally effective but in total there are huge volumes of accumulated salt.

The issues of salt management and its storage in the Murray and Murrumbidgee Basins are nicely summarised in the following excerpt from Jolly et al. (2000).

"For productive irrigation farming to continue, adequate leaching and drainage (to remove salt left in the root zone after transpiration of irrigation water) is necessary (Hoffman, 1985). The natural drainage capacity of the soils and groundwater systems in irrigation areas is usually insufficient to remove water that has infiltrated in excess of crop requirements; and so engineered drainage is often necessary to prevent waterlogging and salinisation of the crop root zone (Tanji, 1996). Surface drains, sub-surface drains, and groundwater pumps act to remove water from the soil profile and allow leaching of salts from the root zone of plants. Drainage can also be used to alleviate high water tables beneath urban areas, and intercept groundwater flowing into streams."

The drainage dilemma

As the salinisation of irrigated areas has become increasingly more serious and widespread, a growing awareness of the link between local catchment and regional salinity issues has led to a re-evaluation of salinity management strategies. In particular, linkages have been made between the use of engineered drainage to reduce and manage the impact of salinisation on local irrigated farmland, and the adverse effects of drainage disposal on the downstream water resources. Such concerns highlight the need to account for local, catchment and regional salinity issues in any assessment of the costs and benefits of irrigated agriculture.

Changing political and community attitudes have increased pressure to minimise the impacts of large volumes of drainage from irrigation areas on downstream users and the riverine environment. As a consequence, drainage disposal into the river system can no longer be viewed as an overall solution to the problems of waterlogging and salinisation in irrigation areas. The costs of rising river salinity in downstream areas need to be balanced against the benefits of upstream irrigation drainage disposal into the river system. To help minimise impacts on the river system, land disposal of drainage to disposal basins has recently become more prevalent. Regional basins have been most commonly used in the past. However, the use of local-scale community and on farm basins is increasing.

The disposal issue

Drainage disposal is one of the most important components in the Land and Water Management Plans (L&WMP) of irrigation areas in the Riverine Plain. However, some types of drainage (surface drainage, rainfall and irrigation runoff) are suitable for reuse and disposal basins will only be viable for disposal of highly saline water because of the high cost of basin construction and loss of productive land. Furthermore, the role of disposal basins in a given L&WMP will depend on the regional context, in particular its salt export situation. For example, the use of basins in a region which has existing external drainage disposal but plans new drainage development will be different to a region which must dispose of all of its drainage to basins.

One of the primary drainage management objectives is to minimise disposal volumes by implementing improved irrigation practices and promoting the re-use of drainage water wherever possible. However, because of the need to prevent salt accumulation in the root zone by maintaining an adequate leaching fraction, saline drainage will always be a consequence of irrigation. It is important to note that all methods of drainage disposal can have negative impacts on the environment. It is therefore important to choose disposal options that minimise the negative environmental impacts and to ensure, as far as possible, that the beneficiaries of drainage pay for its disposal.

Areas of land salinised or waterlogged

It was estimated in 1987 that 96,000 ha of irrigated land in the Murray-Darling Basin were visibly affected by soil salinisation and that 560,000 ha had water tables within two metres of the surface (Murray-Darling Basin Ministerial Committee, 1987b). By the year 2015, it was predicted that 869,000 ha of irrigated land would be salinised or waterlogged due to high water tables. This represents about 60% of the land presently irrigated in the Basin (1.47 million ha; Murray-Darling Basin Commission, 1999). However, recent surveys in New South Wales suggest that these predictions may be too high (A. van der Lely, pers. comm.).

Volumes of drainage disposal required

It is difficult to get an accurate assessment of the total volume of saline drainage produced in the Riverine Plain by water table control measures. L&WMPs for the various irrigation areas of the Riverine Plain provide some information but the data are inadequate to provide an accurate overall estimate.

Nevertheless, it has been predicted that by the year 2040, between 335,000- 608,000 ML/yr of groundwater in the Riverine Plain will require disposal (Gutteridge Haskins and Davey , 1990). The lower value is based on a groundwater extraction rate of 0.7-0.9 ML/ha/year (partial water table control), whereas the higher value considers a groundwater extraction rate of 1.4-1.6 ML/ha/year (full water table control – ie maintain the water table deeper than 2 m). It was also estimated that if the drainage was concentrated to one eighth of its volume and no other means of disposal was available, 29,300 ha (partial water table control) to 53,200 ha (full water table control) of disposal basins would be required. These represent between nine and sixteen times the current area of disposal basins in the Riverine Plain (see Section 2.8). It is important to note that these are probably overestimates as sub-surface drainage is unlikely to proceed in many areas of the Riverine Plain due to the poor financial viability of drainage (A. van der Lely, pers. comm.).

Disposal options: past and present

The main drainage disposal options which are in use or have been considered are:

- by local or regional re-use - with dilution as required;
- to streams and rivers on an opportunistic basis – used in most irrigation areas;
- to disposal basins - in use in some irrigation areas; and
- by a pipeline to the sea - feasibility studies conducted.

Some saline water is currently disposed of into river systems in periods of high flows and thus exported downstream. However, the salinity of pumped groundwater and drainage effluent is such that continuous unmanaged disposal to rivers and streams may result in unacceptable impacts on the environment and downstream users. The Salinity and Drainage Strategy of the Murray-Darling Basin Commission (Murray-Darling Basin Commission, 1999) imposes constraints on the amount of river disposal possible. Moreover, there appears to be declining political and community tolerance of continued disposal to river systems.

Export of saline drainage to the sea via a pipeline is an option which has been considered a number of times in the past (State Rivers and Water Supply Commission, 1978; Earl, 1982; Gutteridge Haskins and Davey, 1990). However, these studies have each indicated that this option was relatively uneconomic when compared with other available disposal options.

Moreover, the potential impacts of this option on the marine environment have not been studied.

Saline disposal basins (also referred to as evaporation basins) have been an important option and will continue to be so into the future, at least in the short to medium term (fifty years). As was shown by Evans (1989), “saline disposal basins are the lowest cost option for disposing of high salinity drainage water.”

Recent developments in all three States have focussed on assessing and developing value add activities associated with saline drainage flows, whether they originate from surface or subsurface drainage of from pumping deeper groundwater. These activities include application to tree lots and salt tolerant species, to salt and mineral extraction, to various forms of aquaculture. All of these activities are in the early stages of development but it is possible that they will become a valuable a useful aid in managing drainage and salt in the future.

Although subsurface drainage has been highly successful in protecting horticultural crops and some dairy pastures the discharges need to be reduced further to meet downstream water quality targets. This will involve better irrigation practices and widespread active management of the subsurface drainage. Overall, the irrigated areas have not yet developed a viable plan for future disposal of saline drainage.

5.4 Nutrients and pesticides from irrigation drainage

Pesticides

Overall, toxic substances are not a serious concern in the Basin, though there have been occasions when such pollutants have had significant local and regional impacts. The runoff from rice and other irrigated grain crops can contain insecticides, pesticides, herbicides and fungicides (see Bowmer et al 1988). The newer chemicals are less persistent and do not accumulate in the fatty tissue of animals, but they are still toxic to fish and other biota, even at low concentrations (Murray-Darling Basin Ministerial Committee, 1996).

In the late 1980s to early 1990s, there were concerns over chemicals in a number of rivers in the central and north western regions of NSW, with high incidences being recorded of the insecticide endosulfan and the herbicide atrazine, both used in cotton growing (Department of Water Resources 1993a). Though the levels were higher than desirable for aquatic ecosystems, they were below the levels acceptable under Australia's national drinking water guidelines. Most problems result from the incorrect use of chemicals and their runoff into streams hence there has been a continuing effort by government agencies to educate and train all those who are responsible for chemical use.
Source: http://www.mdbc.gov.au/naturalresources/env_issues/water_quality.htm

In a major review “Pesticide Use in Australia” (Radcliffe, 2002) the section on pesticides in irrigation areas and surface water concludes,
“In summary, the current pesticides are less persistent than most organochlorines, but such pesticides are still being detected in some surface waters. However residues of pesticides in waterways have often not been monitored from agricultural operations after changes in land use or changes in the spectrum of pesticide usage. Measurement of pesticides in spot water samples may not always be the best method of detecting some pesticides and may not give a clear indication of biological effects.”
There seems to be a clear case for constant and persistent vigilance in trying to minimise pesticide use and in monitoring. Education and training of operators in responsible use seems to be the most effective method of maintaining high standards and minimum pollution.

Nutrient and sediment export

“Dryland regions of the Basin are the primary source for nutrient and sediment export. Unnatural movement of nutrients and sediments across the landscape typically results in the

depletion of these resources in upper and mid-catchment areas and their subsequent concentration in ephemeral channels and waterways. Compensation of lost nutrient and sediment is economically inefficient and continues to exacerbate impacts in lower catchment regions. Identifying movement trends of nutrients and sediments, and establishing long-term solutions which stabilise movement resulting from human activities is important to many broad acre activities."
Source: http://www.mdbc.gov.au/naturalresources/env_issues/environ_issues.htm

While the primary source for nutrient and sediment export into the river systems is from dryland regions, this assessment is based on total load. The evidence from several studies focused on nutrient loading from irrigated regions shows that they can be a significant source of the major nutrients that can potentially encourage algal blooms in the water supplies. Both the original report (Gutteridge Haskins and Davey 1992) and a subsequent more irrigation-focused one (Harrison, 1994) show that nutrient returns can be substantial (P particularly from surface irrigated dairy areas whereas subsurface drainage will likely be higher in N).

Methods to identify the origin of nutrient sources have improved dramatically in the last few years. Awareness of the nutrient loads and the practices that lead to these loads has also improved rapidly so that nutrient management is an integral part of all Land and Water Management Plans.

5.5 Irrigation and soils

Irrigated farming is an intensive user of water and soil. For soils, the frequent wetting and drying, in many cases frequent cultivation, combined with continuous cropping means that structural and chemical fertility can be compromised.

The state of irrigated soils relevant to the regions in this study was reviewed in a scoping study for the Murray-Darling Basin Commission in 2001 (CSIRO Land and Water 2001). The review concluded the following:

"It is clear from the study that a range of issues related to soils are concerning farmers, advisers and research personnel involved in irrigated production systems.

The survey results identified a number of degradation processes across the Basin with an emphasis on:

- soil structure decline,
- soil and water salinisation,
- soil sodicity,
- waterlogging.

These findings were consistent with the conclusions drawn from an overview of likely issues based on an appreciation of the known processes in irrigated soils, and largely accord with Reeve et al (1998) who reported that for dryland agriculture soils, structure decline, organic matter decline and erosion were among the most important soil degradation issues apart from soil salinity and acidity.

In addition to these survey issues, the study team identified a number of other issues including:

- Lack of monitoring under irrigated systems has resulted in very poor understanding of soil conditions and trends, and little or no ability to evaluate the economic costs associated with the various irrigation and soil management practices.
- Increased soil acidity is considered to be a threat, particularly in rice growing areas and other areas where high leaching rates, high nitrogen use and extensive removal of grain, straw and stubble are features.

- Limited knowledge and understanding of water relationships under various soil management and irrigation systems has led to ineffective or poorly designed irrigation systems, particularly those associated with long term designs such as drip and sub-surface drip delivery systems.

The reasons for the lack of monitoring and trend data, and the difficulties in irrigation designs and management may be exacerbated by what is seen as a static skills base of those involved in the industry, lack of consistent guidelines on assessment of soil conditions, and/or the lack of demand/pressure for these aspects to be addressed. The team concluded that there is a strategic need for capacity building in soil assessment and monitoring throughout the irrigation industry. "

However, it is difficult to assess what demand exists for this capacity building. The economic drivers have not been identified for it, and there appear to be no regulatory drivers, particularly at the farm level, where soil management is implemented. This issue should be addressed bearing in mind that there is no agreed standard for the physical assessment of soil condition and, consequently, no agreed economic treatment of soil condition worth.

5.6 Cost of using resources

Most of the impact of degradation on water quality and soil is not currently costed – at the moment most of it is being absorbed by the environment. Where processes of resource change are reversible (e.g. adding salt to water), it may be possible to assign a dollar value for the cost of desalination. Where processes or part processes are irreversible (e.g. soil acidification) we have no way of costing other than to assume some sort of lost opportunity value.

This is where the study of economics and that of ecology (environment) are divergent. The economic justification for intervention in something that will be expressed in twenty or more years is almost never valid yet many of the processes now in train e.g. groundwater discharge will have detrimental consequences well beyond twenty years hence.

6 Linking irrigated productivity with the environmental resource base

Dr Tian Shi and Prof Mike Young of CSIRO Land and Water, Policy and Economic Research Unit, were major contributors to this section.

6.1 Introduction

Irrigated production, like any life system, needs resources. In this case it is primarily water, soil, nutrients and energy along with information and know-how from the people who do the producing. Also, like any production system, there are effects on resources and wastes produced. Without resources in the right quantities and qualities and without proper management of wastes, no production system can continue to operate. The availability of resources will be strongly influenced by the competition for resources and by the operating rules, considered necessary by the wider community for suitable management of resource impact and waste.

Our preceding sections have indicated where, what and how irrigation produces in the Murray and Murrumbidgee Basins and also highlights some of the environmental resources that are affected by irrigated production. The next major section deals with those closely related policy and regulatory conditions that increasingly affect irrigated practice as it re-positions itself in the shared human and natural landscape.

6.2 Irrigation water entitlements and allocations

6.2.1 Background

Across the Murray and Murrumbidgee Basins the terms used to define water licensing arrangements varies among States and the Australian Capital Territory. There is an emerging consensus that:

- a licence indicating how water will be allocated to its holder on a seasonal or other basis should be called an **entitlement**; and
- a volume of water that has been allocated for use or sale should be called an **allocation**.

In South Australia, both entitlements and allocations are called allocations and in Victoria most entitlements are called water rights or diversion licences. In New South Wales, entitlements are often called water access licenses.

6.2.2 Sources of water

Irrigation water in the regions comes from regulated surface water storages, groundwater aquifers and, to a lesser extent, from the capture of overland flows and storage in farm dams.

The amount of water available in each season depends very much on rainfall, land-use in areas that affect runoff and groundwater recharge and perhaps most importantly, the administrative arrangements that determine allocation policies.

6.2.3 Categories and types of entitlements

There is a complexity of different legislative and operational structures surrounding water entitlements and allocations among States. About 93% of total entitlements of irrigators in

NSW are for “general security water”, with “high security water” only used by a small proportion (BTRE, 2003).

As summarised in Table 20, there are thirty-nine categories of water entitlements in the study regions. When all restrictions on use and trade and differences in reliability are considered, there are 438 types of water entitlement in the regulated surface water system of this region (Shi, 2005).

	System	***NSW***	***Victoria***	***SA*** [a]
Entitlement Categories (39)	***Regulated surface water (22)***	Domestic & stock access licence [b]	Domestic & stock right [b]	Stock & domestic licensed allocation [b]
		Local water utility access licence	Town water supply	Metropolitan water licensed allocation [c]
		High security access licence	Supply by agreement	Country town water licensed allocation
		Conveyance access licence	Water right	Industrial licensed allocation
		Environmental water access licence	Diversion licence	Recreational & environmental licensed allocation
		Indigenous cultural access licence	Sales water [d]	Irrigation licensed allocation
		General security access licence		Wetlands licensed allocation
		Supplementary water access licence		Water (holding) licensed allocation
	Unregulated surface water (9)	Domestic & stock access licence	Direct pumping licence	
		Local water utility access licence	Winter fill licence	
		Unregulated river access licence	Farm dam licence	
		Runoff harvesting access licence		
		Indigenous cultural access licence		
		Research access licence		
	Groundwater (8)	Local water utility access licence	Groundwater licence	Water (holding) licensed allocation
		Aquifer access licence	Groundwater licence (irrigation)	Water (taking) licensed allocation
		Supplementary water access licence	Groundwater licence (non-irrigation)	

Table 20 - Overview of existing thirty-nine categories of water entitlements in the regions.

Notes for Table 20:

a. In SA all entitlements are issued as a water licence with a defined purpose. A water licence must be endorsed with a water allocation and a clear distinction is made between water taking allocations and water holding allocations. Water holding allocations are tradable but cannot be used until they are converted to water taking allocations. Recognised water taking purposes include: stock and domestic, metropolitan water supplies, country town water supplies, industrial, recreational and environmental use, irrigation and wetlands.

b. In NSW and Victoria, rights to domestic and stock water allow access in most cases without the need of a license. In SA, the exception applies to riparian users situated directly on the watercourse who can take limited amounts of water (i.e. 500kL) for stock and domestic use without a license.

c. Under Schedule F of the Murray-Darling Basin Agreement, the diversion of water for South Australia's metropolitan Adelaide and associated country areas must not exceed a total of 650 GL over any period of five years.

d. Under current arrangements, opportunities to apply for sales water are attached to water rights and diversion licences and cannot be traded separately. The Victorian Government White Paper on water has proposed to unbundle sales water into a separate, legally recognised, and independently tradable entitlement. In this study, sales water is identified as a separate category of water entitlement.

Table 21 provides a high level summary of the main characteristics and allocation policies of irrigation entitlements in the regions. The reliability value is the number of years in 100 (expressed as a percentage) that entitlement holders could expect to receive the maximum allocation to which they are entitled.

State	Nature of entitlement	Allocation policy	Reliability [a]	Note
NSW	High security access licence	Allocations are specified as a maximum volume and this allocation is expected to be available in all but the worst droughts. Unused allocations are surrendered at the end of the season.	95% (Murrumbidgee) 97% (Murray & Lower Darling)	NSW is in the process of converting all licences into separate access licences as shares and moving all use and work conditions into separate “use approval” and “supply work approval”.
	General security access licence	Annual allocation varies according to the available water amount in the general security allocation pool, after allocating to higher priority pools (e.g., water utilities, the environment, stock and domestic uses, high security access licence holders, etc). Carry-over and overdraw provision rules apply to general security entitlements only.	70% on average	
	Supplementary water access licence	Available to general security access licence holders only when flows are surplus to in-stream requirements.	Opportunistic	
Victoria	Water right	A high reliability entitlement held by individuals within irrigation districts. Allocations are specified as a maximum volume and this allocation is expected to be available in all but the worst droughts. Some, but not all, water right holders have access to sales water. Unused allocations are surrendered at the end of the season.	96-99%	Following NSW, Victoria has announced an intention to unbundle the entitlement dimension of a water right or diversion licence from use conditions and manage them separately from allocations.
	Diversion licence	Issued for a specified annual volume and (usually) a maximum diversion rate. Unused allocations are surrendered at the end of the season.		
	Sales water attached to water right [b]	When seasonal conditions and dam supplies allow, sales water allocations may be purchased by an irrigator in addition to those available under a water right. Sales water is not available to water right holders in the western part of Victoria. Unused allocations are surrendered at the end of the season.	68% [c] (Murray) 43% [c] (Goulburn)	Sales water attached to a water right is more reliable than that attached to diversion licences.
	Sales water attached to diversion licence [b]	Allocation policy dimensions are the same as above.	48% [c] (Murray) 30% [c] (Goulburn)	

State	Nature of entitlement	Allocation policy	Reliability [a]	Note
SA	Water (taking) licence	Allocations are specified as a maximum volume and are expected to be available in all but the worst droughts. Unused allocations are surrendered at the end of the season. 'Taking' allocations include permission to use water at a specific location.	Almost 100% [d]	Water 'holding' allocations are tradable but cannot be used until they are transferred to water 'taking' allocations.
	Water (holding) licence	Allocations do not vary from year to year and are expected to be available in all but the worst droughts.		

Table 21 - A summary of state approaches to surface water allocation.

Notes for Table 21:

a. Data were derived from Ballard (2003).

b. Under current arrangements in Victoria, sales water is not a formal entitlement. It is attached to water right or diversion licence and cannot be traded separately.

c. The reliability of sales water is approximate and reflects the probability of reaching full sales allocation.

d. In 2003/4 and 2004/5, SA water licence holders have not received their full allocation. This is the first time happened in history.

Some people regard NSW high security water as more secure than Victorian water because most water in Victoria is allocated as "general security" water. In recent times, however, NSW high security entitlement holders have not received their full allocation. In NSW only, general security entitlement holders can carry forward water up to their full entitlement volume to the following year which means that water not used in the current year can be used in the following year - in addition to their allocation for the following year.

6.2.4 The 'Cap'

Allocation and entitlement policies in each State are managed by a Murray Darling Basin-wide process that seeks to limit the total amount of water that is 'used'. Under this arrangement – known as the 'Cap' – States are free to allocate as much as they like but must ensure that less than the Cap is pumped or diverted from the system (see Box 1). In some, but not all areas, surface drainage returns (but not groundwater returns) are included in the accounting rules.

From 1988 to 1994, water consumption in the Basin increased by 7.9% overall. By 1994, water consumption in the Basin had reached 10,780 GL per year, which had grown from approximately 2,000 GL a year in 1920 (Murray-Darling Basin Commission, 2000). In response to the increasing levels of diversions and the consequent decline in river and riverine health, the MDB Ministerial Council, at its June 1995 meeting, decided to introduce an interim Cap to limit the level of water diversions from the Basin.

The Cap was defined as the volume of water that would have been diverted under 1993/94 levels of development (Murray-Darling Basin Commission, 2000).

In the Murray and Murrumbidgee Basins, the Cap is approximately 8,734 GL.

Box 1 – The history of the Murray Darling Basin "Cap"

Figure 32 summarises the nature of allocations and cap arrangements in the study regions. Diversions are less than allocations as not all water is used or traded. As restrictions on trading have been removed, States have had to reduce allocations so as to keep their total water use within the Cap agreement.

The Australian Capital Territory and Queensland have not yet agreed to the Cap and, at present, limits diversion to that needed for urban and industrial use plus a small amount that is used by irrigators.

The Cap does not a set an annual limit on the amount of water a State can divert for use. Rather, it is a long term, average diversion of water from the Murray-Darling River system, with yearly levels varying with climatic and hydrologic conditions (see Figure 32). However, it is up to each state to decide how this water is shared among users each year (including the environment). The aim of the Cap is not to restrict development, but rather to create an environment where any water needed for increased development is required to come from

(1) improving water use efficiencies, and/or

(2) by purchasing water from existing entitlement holders.

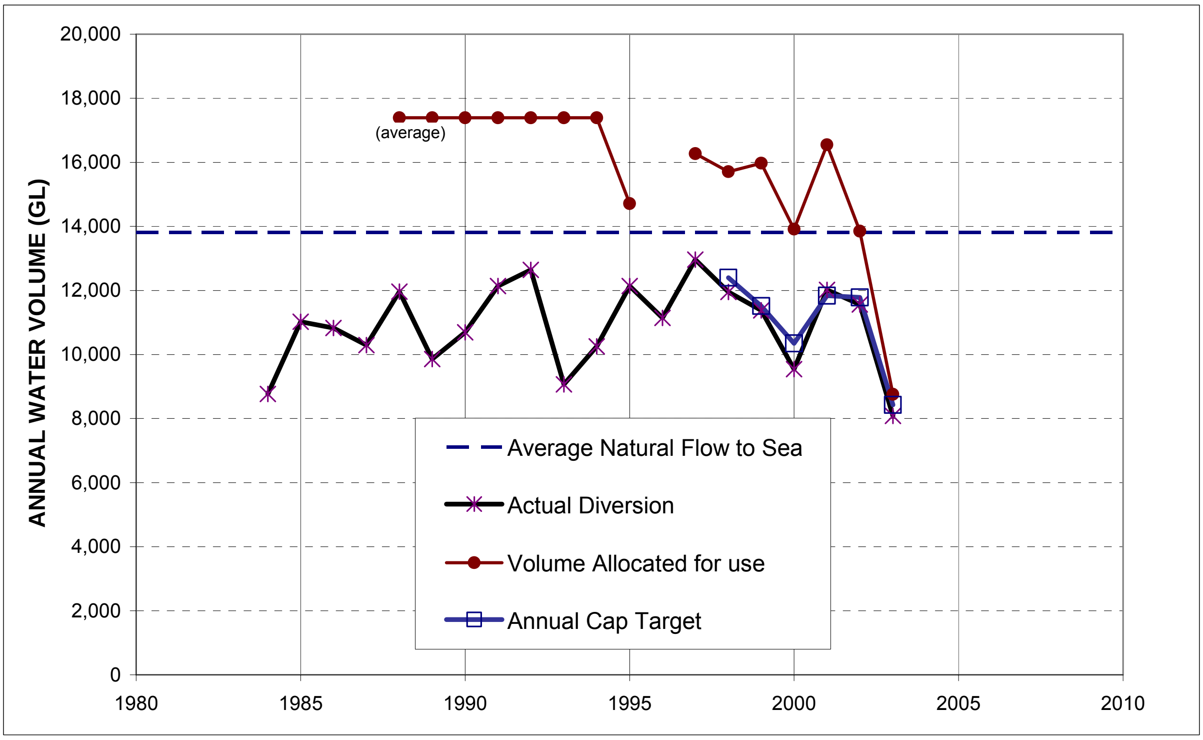


Figure 32 - Diversions from the Murray and Murrumbidgee connected river system, the sum of all allocations and the average cap. Source: Prasad, A. Murray-Darling Basin Commission, Pers. Comm., 2005.

6.3 Water trading

6.3.1 History of water trading

Across the Murray and Murrumbidgee Basins, both irrigated entitlements and allocations in regulated surface water systems are tradeable. Trading arrangements for groundwater are much more limited and trading in farm dam entitlements is in its infancy.

Since the Council of Australian Governments (COAG) meeting in 1993/94 that resolved to encourage the separation of water entitlements from land titles, there has been a considerable increase in water trading (see Figure 33). The main reasons for allowing this were to encourage water use in locations and practices that returned greater economic value and to allow its transfer away from areas where use was causing unacceptable environmental problems.

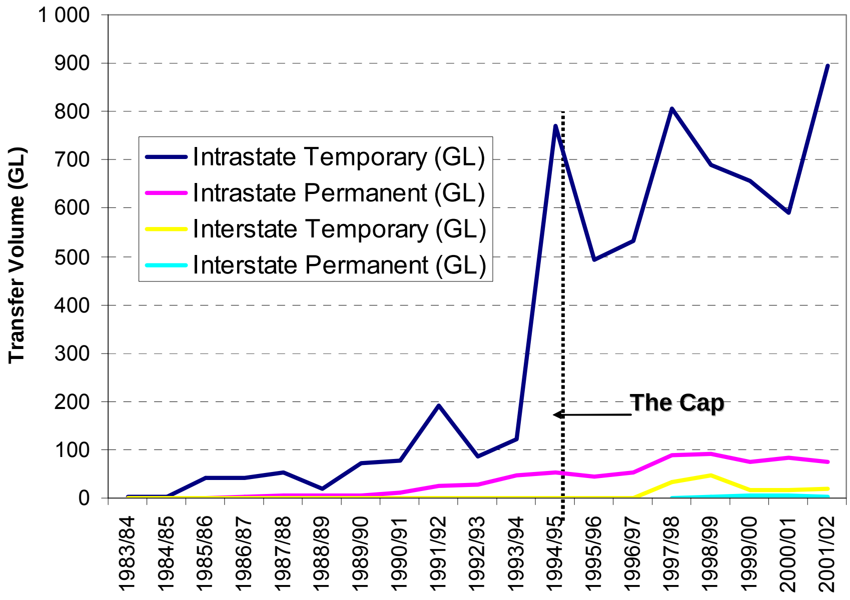


Figure 33 - Increase in temporary and permanent trading in the MDB

Trading has occurred on a limited basis in the Murray-Darling Basin since the 1940s but significant active trade in the Basin has only occurred since the 1980s.

Temporary water trading has existed since 1982 in SA, 1983 in NSW and 1987 in Vic. Permanent water trading within States has existed since 1982 in SA, 1989 in NSW and 1991 in Vic (SMEC, 2001). There has been a big increase in water trading since the mid-1990s (e.g. up to 90% of irrigators involved in some valleys) and interstate trade commenced in the mid-1990s (temporary ’94; permanent ’98).

Permanent trade of water between States started in September 1998 primarily via a Murray Darling Basin Commission (Murray-Darling Basin Commission) Pilot Interstate Water Trading Trial Project. This project is limited to areas downstream of Nyah in Victoria and only for high security water entitlements (see Figure 34). Exchange rates encourage trade downstream and penalize upstream trade.

Figure 34 - Location of the pilot interstate water trading project that allows trade of water between Nyah and the River Murray mouth.

Table 22 summarises the recent interstate trades in water entitlements that have occurred as a result of the Pilot Interstate Water Trading Trial project. The trade has clearly resulted in a net movement of water downstream and is linked closely with water being used on high value fruit and grape crops in the Riverland and Lower Murray areas of SA.

	NSW	VIC	SA
1998-99	2747	351	(3098)
1999-00	3016	2214	(5230)
2000-01	176	3099	(3275)
2001-02	(222)	2797	(2575)
2002-03	(274)	503	(229)
Total	5443	8964	(14407)

Table 22 - Net permanent trade in water entitlements by State (unit: ML). Source: Peterson *et al.*, 2004.

Note: Figures in parentheses denote imports.

6.3.2 Allocation trading

Across the regions the trading of allocations, most commonly called "temporary trading", is well developed. A significant number of water brokers are now involved in this business and prices vary in response to seasonal conditions. Three internet-based trading systems now operate under the names "The Water Exchange", "Water Find" and "Water Move".

Allocation (temporary) trading is now common and in many areas more than half of the irrigators have been involved in at least one water trade (see Table 23).

Irrigation area	Proportion of farm businesses
Pyramid Hill/Boort (Victoria)	89%
Torrumbarry/Boort (Victoria)	65%
Murray Irrigation Limited (NSW)	88%
Private Diverters Murray Region (NSW)	73%
Private Diverters River Murray SA (Riverland)	39%
Private Diverters River Murray SA (Lower Murray)	55%
Central Irrigation Trust (SA)	15%
Based on inspection of water access entitlement registers and water trading registers up to 30 June 2001. Source: Bjornlund, 2002.	

Table 23 - Proportion of irrigation farm businesses that have participated in the water market by area in selected parts of the River Murray.

(Extracted from 2002/2003 Water Audit Monitoring Report, Murray-Darling Basin Commission 2004. p42)

"It is expected that diversion as a percentage of the water authorised to be diverted will fluctuate from year to year, depending upon the climatic conditions and the degree to which the diversions are constrained by the physical resources available. Typically the utilisation of the allocations will be higher in drier years and lower in wetter years. It is also expected that allocations would reduce and use increase, if the allocation system was tightened to prevent growth in diversions under the Cap.

"In this context, the 92% use of Basin allocations in 2002/03 is higher than the average of 63% reported for the 5 years to 1993/94 in the “1995 report to the Ministerial Council: An Audit of Water Use in the Murray-Darling Basin”. 92% use is the highest since Cap accounting started in 1997/98. This is partly due to very dry conditions during 2002/03 and partly due to tightening of the allocation system. In previous years utilisations were 83% (2001/02), 73% (2000/01), 69% (1999/00), 71% (1998/99) and 76% (1996/97 and 1997/98)."

Box 2 - Comparison of diversions with water authorised for use

6.3.3 Entitlement trading

Entitlement transfers between river systems and more complex interstate trading requires consideration of such aspects as ‘the Cap’, state entitlements, biophysical constraints (e.g. the limitation of downstream flow because of channel capacity such as the Barmah “choke” on the River Murray upstream of Echuca), transmission losses and environmental considerations.

It is also necessary to determine whether or not all registered interests, such as a mortgage, have been cleared. New South Wales is in the process of separating access entitlements from use approvals so that trades can occur without consideration of the environmental implications of using water at any location. In a white paper on water management, Victoria has announced that it intends to adopt a similar approach.

At present, Victoria has in place a series of arrangements designed to encourage the trade of water entitlements out of areas where salinity is a problem (see section 6.4.2).

6.3.4 Other forms of trading

In addition to entitlement and allocation trading, a number of other forms of trading are occurring and under consideration. The most common of these is the leasing of an entitlement to another location. Some leases take the form of a private contract and are executed by a series of temporary trades when the contract becomes due. Other leases are registered with State administrators and pre-approved.

As trading becomes more common, complex leasing and other arrangements are being put into place in order to optimise stamp duty and income tax considerations. Among other things, the sale of an entitlement is subject to capital gains tax, while the cost of purchasing an allocation can usually be deducted in the year of acquisition.

Recently, there has been considerable discussion about the introduction of tagged entitlement trading arrangements. Under this arrangement, water is transferred to a new location but retains the features of allocations and entitlements at its previous location. In effect, this is the same as a lease but ownership of the entitlement is transferred to a person who is granted prior approval in perpetuity to transfer all allocations received to the new locations.

Three features differentiate tagged trading arrangements from a permanent entitlement trade. First, the entitlement remains on its original register and all charges associated with holding and dealing with the entitlement remain payable. Second, variations associated with the future modification of any exchange rates used to adjust for transmission losses are at the risk of the person who holds the tagged entitlement. Third, any changes to allocation plans etc made at the source of a tagged entitlement affect the volume of allocations available at the place where the tagged entitlement is now used.

In short, the risk of any changes to financial, volume reliability and exchange rate arrangements are borne by the tagged entitlement holder.

6.3.5 Trading patterns

The flow of permanent trade in water entitlements is generally from east to west in response to a large array of markets, investment opportunities and administrative arrangements. Most permanent water entitlement trades have involved the transfer of water which, in the past, has not been used by the entitlement holder (Young et al. 2000, BTRE, 2003).

Figure 35 summarises the pattern of permanent and temporary trading in South Australia. As is the case in all States, there is more trading within the State than there is among States. While there have been more permanent trades into than out of South Australia, when the impact of temporary trades is considered the pattern in two of the last three years has been reversed. More water has left than has entered the State. This may be due to people buying water in order to facilitate new irrigation development and are trading the water back on a temporary basis until it is needed for the new development.

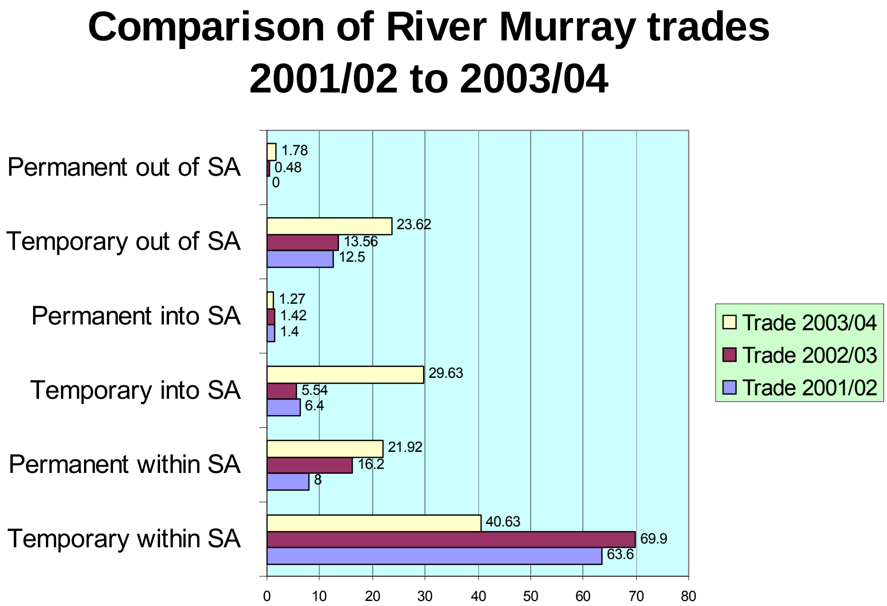


Figure 35 - Summary of water trading in South Australia over last three years (units are GL per year)

In some cases, water is now beginning to transfer from established irrigation areas to other locations where it can be used more profitably. Areas where this is occurring include the Lower Murray Swamps in South Australia where a number of dairy farms have closed and their water transferred elsewhere, and the Kerang-Pyramid Hill area where salinity is a serious problem. One attraction of trading is that people in such a situation receive a much higher price for the water asset they own than would otherwise be the case.

Recently in South Australia water has been purchased from irrigators for urban use (Young and McColl 2004).

The development and expansion of water trading in the Basin has contributed to:

(1) new irrigation development;

(2) regional growth (e.g. Riverland, Sunraysia);

(3) industry sector expansion (e.g. vineyard); and

(4) increased value of irrigated agriculture and increased returns to irrigators (ie low value to high value use).

It is anticipated that irrigated areas in SA, using River Murray water, will expand over the next ten to twenty years, predominantly in vines, citrus, tree crops and vegetables (Department of Water, Land and Biodiversity Conservation, 2002), by using water traded into SA and more efficient use of existing entitlements to cover a larger area. But changes in water entitlement and allocation arrangements foreshadowed in other States may result in this anticipated expansion occurring there rather than in South Australia.

The general trend in Victoria is a permanent movement of water entitlements north and west, towards low salinity impact irrigation areas around Mildura (BTRE, 2003). Over a thirteen year period to 2003/2004, the permanent movement of water out of northern Victoria has only been 64 GL (Table 24), with most coming from the Pyramid-Boort region as indicated above.

Summary of water trade in northern Victoria							
Permanent trade summary over 13 years		**Permanent trade price**		**Goulburn Temporary water trade**			
Region	**Change**	**Year**	**Price ($/ML)**	**Year**	**Allocation**	**Trade as proportion of allocation**	**Price ($/ML)**
Torrumbarry	-8.60%	1998/99	$822	1995/96	150%	7%	
Murray Valley	-0.10%	1999/00	$770	1996/97	200%	4%	
Shepparton	-2.60%	2000/01	$710	1997/98	120%	9%	
Central Goulburn	-1.40%	2001/02	$705	1998/99	100%	13%	$65
Rochester	3.00%	2002/03	$1,130	1999/00	100%	14%	$56
Pyramid-Boort	-11.00%	2003/04	$1,235	2000/01	100%	15%	$34
Goulburn - Murray Water	-3.90%			2001/02	100%	13%	$100
Total net loss	64,000 ML			2002/03	57%	30%	$364

Table 24 – Summary of water trade in Northern Victoria. Source: G. Earl, Pers. Com. Feb. 2004.

However, an increasing perception is that the future amount of water available for irrigation will be severely reduced due to increased demand for environmental flows through initiatives such as “The Living Murray”. At present, demands for this water are being met from investment in the upgrade of infrastructure in New South Wales and Victoria and also in reductions in allocations to Victorian irrigators. In the not too distant future, however, cost-effective investments of this nature are likely to be exhausted and governments will probably need to begin sourcing water for environmental allocations from irrigators.

There are a number of ways that this could be achieved. Options range from pro-rata reductions, through compulsory acquisitions, to calls for donations and market buy-back schemes. It may also be possible to enter into agreements where irrigators contract to supply water in wet periods to the environment but have first call on it during dry periods. Conversely, it is possible for an environmental manager to hold an irrigation entitlement and then manage it counter cyclically, selling some allocation back to irrigators in dry periods and buying more during wet periods. All options are possible, especially as many irrigators are holding water entitlements surplus to immediate requirements as a means to hedge against temporary water shortages and as a long term investment.

6.4 Trade in water within the irrigation industry

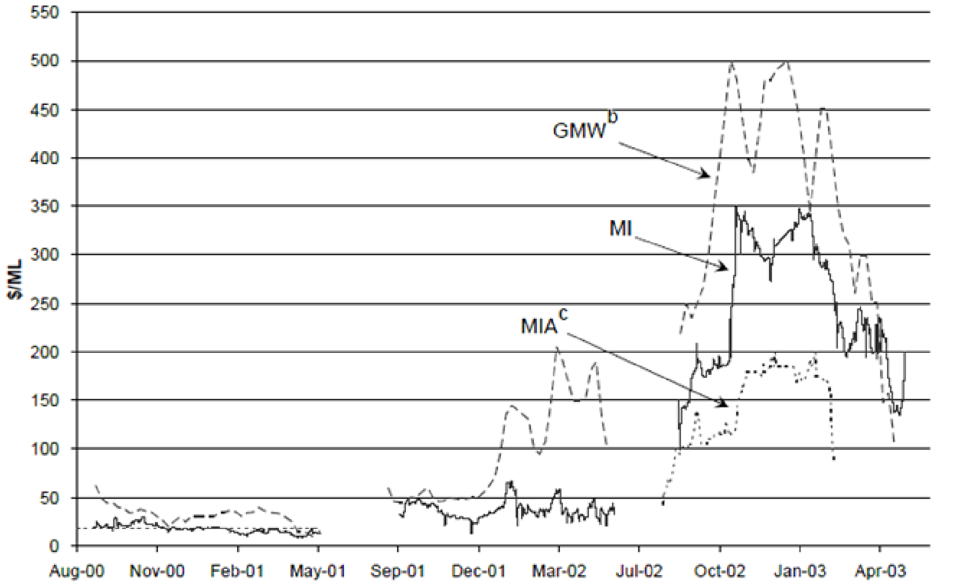
6.4.1 The economic and social impacts of trading

As a general rule, most empirical research suggests that the economic and social impacts of trading are less than many public comments would suggest. The reasons for this include the fact that trade means that the price for water is greater than it would be if it were sold with the land and that water trading is often associated with an increased investment in technology and infrastructure.

To illustrate this point, a recent Productivity Commission report observed that trading nearly halved the impact of a 20% reduction in water allocations on the value of gross regional production in the regions from -1.04% to -0.52% (Peterson *et al.* 2004). In a separate study, Young *et al.* (2002) observed that most of these effects would be offset almost completely if such a reduction increased water productivity (kg / ML) in the horticultural sector by 0.25% per year and all other irrigation by 0.5% per year.

6.4.2 Trading incentives

Trade always involves willing sellers and buyers and there are many reasons why people wish to trade. Opportunities to profit are considerable but also require careful consideration of income and capital gain taxation implications. As can be seen from Figure 36, in many parts of the regions the market is now well developed and temporary trade prices reflect the nature of the short term value of water. As general security allocations in New South Wales can now be carried forward, the base price for most trades reflects the value of water in subsequent years.



[a] Average weekly pooled price per megalitre; MIA price for 2000-01 is a yearly average. [b] GMW data for the Greater Goulburn subdistrict. [c] MIA data for 2001-02 were not available.

Data sources: Goulburn-Murray Water, pers. comm., 1 December 2003; MI, pers. comm., 22 December 2003; MIA, pers. comm., 2 February 2004.

Figure 36 - Average weekly prices per megalitre for traded allocations in major irrigation districts in the regions. Source: Appels et al. 2004.

Trading opportunities are, however, restricted by the need to obtain an environmental or "use" approval before water may be used. In some States, this must be done on a trade-by-trade basis, while in other States, approval can be obtained in advance. The move towards the separation or unbundling of licences is starting to simplify the process of obtaining approval to buy in water as and when it is needed.

In Victoria, a series of trading zones is used to prevent the trade of regulated surface water into areas where the result would be an increase in river salinity. The essential requirement is that water currently in a high impact zone must be traded to one of four low impact zones. Trade from a high impact zone to any of the four low impact zones does not attract a levy while trade among low impact zones attracts a levy that depends upon the net impact of the trade. The highest charge for permanent trades is $260 per megalitre and the lowest is $26 per megalitre. The temporary trade salinity levy creates a similar incentive (see Table 25).

Trade from	Trade to									
	LIZ 1		LIZ 2		LIZ 3		LIZ 4		HIZ	
	Temp	Perm	Temp	Perm	Temp	Perm	Temp	Perm	Temp	Perm
Outside area	$2.60	$26.00	$6.50	$65.00	$13.00	$130.00	$26.00	$260.00	No trade	No trade
LIZ 1	$0.00	$0.00	$3.90	$39.00	$10.40	$104.00	$32.40	$234.00	No trade	No trade
LIZ 2	$0.00	$0.00	$0.00	$0.00	$6.50	$65.00	$19.50	$195.00	No trade	No trade
LIZ 3	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$13.00	$130.00	No trade	No trade
LIZ 4	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	No trade	No trade
HIZ	No trade	No trade	No trade	No trade	No trade	No trade	No trade	No trade	No trade	No trade
Source: Lower Murray Urban and Rural Water, http://www.srwa.org.au/index2.htm										

Table 25 - Summary of salinity levy payable for permanent trades (Perm) and temporary trades (Temp) in Victoria from Nyah to the border for Low Impact Zones (LIZ). No trade is allowed within or into a High Impact Zone (HIZ).

6.4.3 Barriers to trade

At present, there are a considerable number of so-called “barriers” to trade (Hassall & Associates with Musgrave 2002). Some of these barriers are there for historical reasons, some in an attempt to protect regional interests and some because of the ways that water entitlements, allocations and use conditions have been defined. Administrative processes and costs are another reason that trade is less than it could be.

Timing restrictions

Several of the barriers in place are due to the fact that in NSW it has been common practice to allocate more water than is available under “the Cap” but then restrict temporary trading so that not all water can be used. In other States, there are no restrictions on the timing of a trade. One example of such an arrangement is the DIPNR requirements that trading be announced in advance. For example, to trade the allocation made at the start of a season out of the district, an announcement of this intent must be made before 2nd August. Trades made without announcing the intent attract a 1ML for 1ML penalty. Similar arrangements apply for trades into the zone, although these are less restrictive.

Volume restrictions and stranded assets

One of the most commonly stated reasons for districts and irrigation companies opposing trade is the concern that trade will reduce the use of infrastructure and leave those who continue to apply water in the area with a higher share of the operating cost for use of irrigation channels and the like. Known as the "stranded assets" problem, there is now discussion as to whether or not those who trade water out of a district should be required to pay an exit fee. One pragmatic option is that this fee should be in the vicinity of ten times the usual operating and maintenance fees paid by a licensee.

Another approach being used to restrict trading is the placement of a quota on the volume of water that may be traded out of a district.

Directional restrictions

At the time of writing, all irrigation districts seem to be prepared to allow water to trade in but many have placed restrictions on trade out of the district. A number of Victorian and South Australian irrigation areas place a 2% limit on the volume of water that may be traded out of the district in a year. COAG's recent National Water Initiative, however, requires that these limits, where they exist, be increased to 4% per annum by June 2005.

Fees and charges

Another barrier to trade is the wide array of fees and charges associated with both the use of water and also trade in water entitlements and water allocations. While the permanent transfer fee in all States ranges from $225 in Victoria to $255 in South Australia, there is a much wider range of charges for temporary transfer:

NSW charges $25 per ML up to a maximum of $75;

South Australia charges $255 per trade;

Victoria charges between $65 and $75 per trade.

At present, South Australia is the only state that charges stamp duty on a transaction at a rate that varies from 1% to 5.5% of the value of a transaction. At this rate, the permanent transfer of 500ML of water would attract just over $30,000 in stamp duty which is equivalent to an additional charge of $60 per ML.

6.4.4 The National Water Initiative - trading principles

At its 25th June 2004 meeting, COAG resolved to implement a National Water Initiative which, amongst other things, proposes a set of trading principles that are designed to remove barriers to trade. In part, Schedule G proposed that:

- Water access entitlements may be traded … where water systems are physically shared or hydrologic connections and water supply considerations … permit.
- Restrictions on extraction, diversion or use of water resulting from a trade can only be used to manage:
    - environmental impacts, including impacts on ecosystems that depend on underground water;
    - hydrological, water quality and hydrogeological impacts;
    - delivery constraints;
    - impacts on geographical features (such as river and aquifer integrity); or
    - features of major indigenous, cultural heritage or spiritual significance.
- Exchange rates will not be used to achieve other outcomes such as to alter the balance between economic use and environmental protection or to reduce overall water use.

6.5 Water use efficiency and water use productivity in irrigation

Dr Evan Christen and Dr Nihal Jayawardane, CSIRO Land and Water, were major contributors to this section.

6.5.1 What is water use efficiency and water use productivity?

The aim of irrigation is to supply water to maximize crop yield. Water, needed for crop growth can be lost as it is conveyed from the storage source via channels to the farm gate, during application to the crops on farm and during its use by crop plants to produce biomass and crop yield. The ratio of water measured at the farm gate relative to that released from the storage can be termed the conveyance “efficiency”. The ratio of the water that enters the soil volume and root zone and is available for plants relative to that measured at the farm gate can be termed the application “efficiency”. The ratio of saleable product relative to the amount of water applied e.g. kg of grain per ML of applied irrigation water can be termed the water “productivity”. Collectively these measures can be referred to as the water use efficiency and productivity (WUEP) of an irrigation scheme.

Appendix 4, “Measuring water use efficiency and water use productivity” gives a more comprehensive account of how these two aspects of irrigation effectiveness are determined.

Engineering definitions of water use efficiency and water use productivity

Efficiency is defined as the rate of conversion of input into a specified output (Smith 2000, Schmidt 2001), and is given by the ratio

Water use efficiency = water output / water input

By definition then, an efficiency ratio is one in which the measured items and their units are the same. For example, the input amount of water from storage to a channel system (ML or m^3) relative to the output amount of water at the farm gate (ML or m^3).

The engineering focus is mainly on the efficiencies of the transfer or conveyance process. In conveyance processes, the inputs and outputs have the same units and hence the efficiency is a dimensionless unit. The agronomic focus is mainly in the conversion process of water to plant products as a productivity measure, and therefore the units of the inputs and outputs differ. Thus, the term water productivity, which involves a conversion process, is defined as the effectiveness with which crops use water to produce biomass or crop yield, and is expressed in units of production per unit of water such as kg m^{-3}. Hence,

Water use productivity = Amount or value produced / amount of water used

6.5.2 Example application of measuring water use efficiency and productivity in the Murrumbidgee Irrigation Area

The modified WUEP framework was applied to existing farm water use survey data for a selection of annual crops (Tijs, 1998, 2001). This crop data was split into two groups; rice and non-rice, to look at the difference between ponded paddy rice and other crop types.

For rice farming in the MIA, implementation of the rice irrigation water use target in 1985 aimed to move ponded rice-growing areas onto lands with lower percolation losses, has led to a marked increase in rainfall + irrigation efficiency from around 0.83 to 0.92. The potential for further increase in this WUEP parameter appears to be small. Combining agronomic measures to increase rice yields with implementation of strategies to limit ponded rice cultivation to suitable soils with low permeability has also increased rice Water Productivity from 4.2 kg/mm to 6.0 kg/mm. There is potential to further increase rice Water Productivity by increasing rice yields with improved agronomic management.

Many other non-rice crops are grown on clay soil of relatively low to moderate permeability, sometimes in rotation with rice. Data from the period from 1997 to 2002 indicates that mean rainfall + irrigation efficiency varied from 0.65 to 0.75 with different crops, with a mean of 0.69 for all non-rice crops. The winter crop yields appear to be highest in the moderate rainfall years, with a tendency towards a decrease in crop yields with a higher growing season rainfall. The Water Productivity for non-rice crops are below the maximum values observed in other areas, indicating the future potential for increases.

As observed previously, the detailed farm data in this case study of the MIA showed that the WUEP parameters calculated for the non-rice cropping in the area are determined by the complex interactions of on farm factors, especially improved irrigation layout and agronomic management. Thus, the future potential for achieving on farm water savings as well as the appropriate technologies required varies widely for different farming enterprises.

6.5.3 Change in water productivity over time

There are very few examples of irrigated commodities that have tracked the change in water productivity over time. As indicated above, rice is an exception with the improvement in productivity over the last twenty years illustrated in Figure 37.

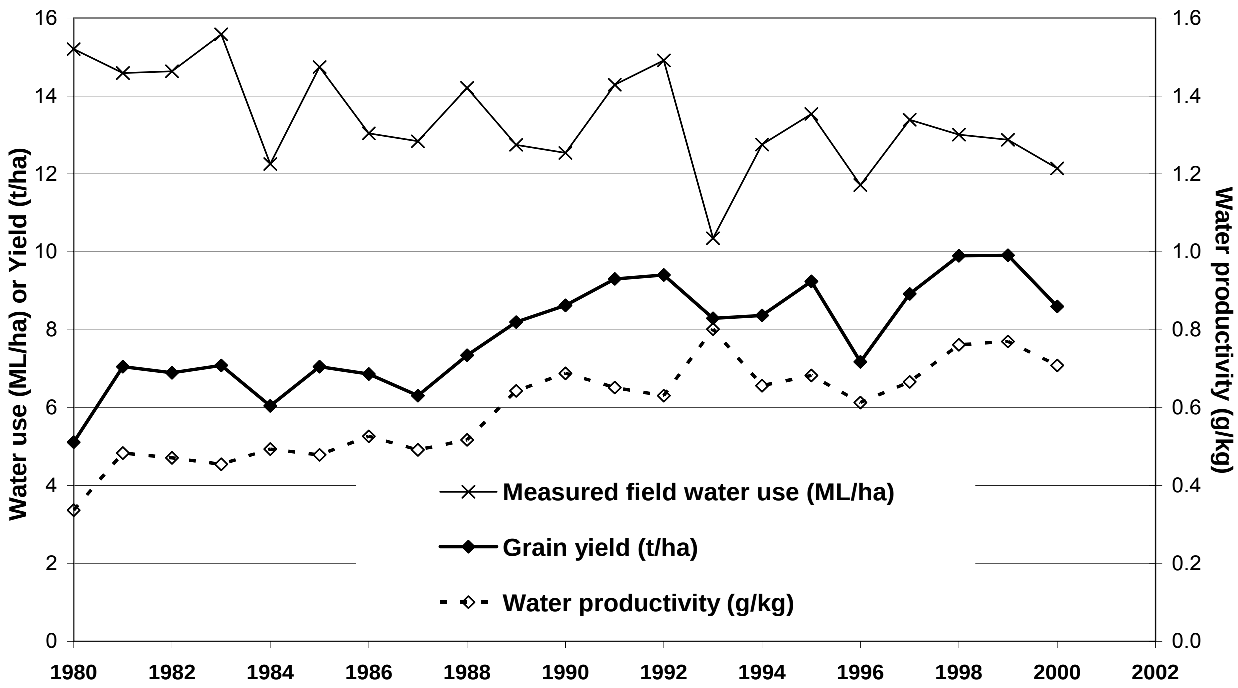


Figure 37 – Change in grain yield and water use in rice over the 20 year period to 2001 with the derived change in water productivity. Data and Figure from Humphreys et al 2003. Note: units of g/kg x 1000 = kg/ML.

Several recent studies of the irrigated dairy industry in northern Victoria (Armstrong et al 2000, Linehan et al 2004, and Melsen et al 2004) have shown the tremendous variation that exists between dairy farm water productivity – a situation that is consistent with the citrus example given in section 4.6. The survey of 170 farms between 1994 and 1996 produced water productivity values with a range from 25 to 115 kg milk fat per ML of irrigation water. A similar, although smaller, survey in 1997 to 1999 indicated that while there had been significantly different water availability conditions between the two survey periods there was no consistent evidence to indicate that limited water had improved water productivity. The Melsen et al (2004) study focused on two case study farms for which long term records had been kept. The indications are that there was a small but gradual improvement in water productivity between 1967 (45 kg milk fat /ML) and 1991 (90 kg milk fat / ML) and that this increased to 150 kg milk fat /ML in 2002. However, as Melsen et al .point out this later rise is primarily due to the dairy farmer bringing in additional supplementary feed. The amount of irrigation water and productivity from the irrigated pasture is unlikely to have changed significantly. There appears to be some evidence of improved water productivity in dairy but given the complexity of the feed and animal interaction there is need for greater consistency in collecting the data so that we can be sure of the trend.

Other commodities have variable information on change in water productivity but none have collected this in a consistent manner similar to that of rice. A paper by Meyer in 1997 compared water use and energy conversion efficiency from data over 30 years (Table 26). This demonstrated that water productivity had improved in all commodities and that the major reason was increased yield rather than a consistent decrease in the water used to produce this yield. Similar anecdotal evidence comes from irrigated almonds in the Riverland and Sunraysia regions (Tony Read, Pers. Comm. 2005). In 1987 yields were about 2.7 tonnes per ha using 13 ML/ha of water. It is expected that in 2005 yields will be closer to 4 t/ha with 15 ML/ha of water use. This means that water productivity has risen from 208 to 267 kg/ML an improvement of 28% over an eighteen year period. Data from the Sunraysia region for the period from 1998 to 2003 (Giddings 2004) shows that as improved irrigation delivery and application systems come into effect so the annual application of water decreased. For example, in comparable evapotranspiration and rainfall years of 1998/1999 and 2002/2003, the amount of water applied decreased from 4.56 kL/mm of evaporation minus rain down to 3.7 kL/mm, a decrease of 19%. Unfortunately, there is no accompanying yield data but almost certainly this would have improved in line with other agronomic observations.

Crop	Year	Yield (kg/ha)	Water use (ML/ha)	Water productivity (kg/ML)
Grapes (white)	1960	25172	10.7	2353
	1990	30000	8	3750
Oranges (fresh)	1960	30206	12.2	2476
	1990	40000	15	2667
Rice (white)	1960	5096	15.2	335
	1990	5850	12	488
Wheat (flour)	1960	911	4.6	198
	1990	3750	5	750
Tomatoes (fresh red)	1960	50300	9.1	5527
	1990	80000	8	10000

Table 26 – Example of increased water productivity over time for selected commodities. Adapted from Meyer (1994).

While we have been able to gather some data for commodity water productivity, it is clear that most recording systems are quite inadequate to enable a confident assessment of progress over time. There is certainly enough evidence to show that improvement is occurring, there is also enough evidence to demonstrate that there is still a very wide range of performance at farm enterprise level. Improvement is occurring and further opportunities for additional improvement are certainly indicated.

6.6 Water Balance to Realise True Water Savings

Prof. Shahbaz Khan, Charles Sturt University and CSIRO Land and Water, was the major contributor to this section.

6.6.1 Introduction

This section is based on the results of a study commissioned by the Pratt Water Group as part of the Murrumbidgee Valley Water Efficiency Feasibility Project. CSIRO was commissioned to identify the potential to save water in the Valley and the full results of this study are contained in the main report (Khan et al, 2004a).

This summary represents a synthesis of the findings in the main report with occasional reference to another CSIRO - Pratt Water Working Paper, *"Whole of Catchment Water and Salt Balance to Identify Potential Water Saving Options in the Murrumbidgee Catchment"* (Khan et al, 2004b). The following information needs to be read in the context of the larger study but the main findings are summarised here.

6.6.2 The need for water savings

With water resources in irrigation areas being close to fully allocated, or even over-allocated, there is keen competition for the water that is available. The recent drought has exacerbated this situation and it is increasingly being accepted that in southern Australia there will be less total water available for irrigated agriculture in future. This realisation is driving the increasing value being paid for water access transfers, it explains the increased use of groundwater that has occurred in the last few years and it provides impetus to the imperative of conveying and applying water very efficiently and using it very effectively.

The Khan et al. (2004b) study on the salt and water balance in the Murrumbidgee Valley, using 100 years of data from various sources, tracked the total flow through the system from the Blowering dam wall to Balranald. The study differentiated between true losses and apparent losses using the following equation:

Net gain/loss = outflow – (inflow – diversions – evaporation)

Unaccounted losses in the Murrumbidgee system are summarised in Table 27.

Component of system	Unaccounted flows (GL/year) DIPNR models	Unaccounted flows (GL/year) 1990-1999
		Loss
The River System	405	360-904
Dams - Wagga Wagga	25	
Wagga Wagga – Narrandera	170	37-90
Narrandera - Darlington Point		34-386
Darlington Point - D/S Hay Weir	120	48-485
D/S Hay Weir – D/S Maude Weir	190	30-208
D/S Maude Weir – D/S Balranald Weir		19-315
Evaporation (Accounted True Loss from River)		70-80

Table 27 - Estimated unaccounted flows in the Murrumbidgee Valley.

Note: DIPNR refers to the NSW Department of Infrastructure, Planning and Natural Resources

True water losses are water lost by evaporation from channels and rivers or through seepage from supply systems and farms into saline water tables. Once lost, this water cannot be directly recovered within the region for irrigation purposes. Apparent losses are not losses but movement of water from one system to another such as percolation into deep aquifers and movement from the river into adjacent aquifers.

True losses and potential water savings within the irrigation areas for the whole system are summarised in Table 28 below.

Component of system	Accounted and identified for water savings (GL/year)			
	Near-farm[1]		On farm[2]	
	Previous knowledge	*New assessment*	*Previous knowledge*	*New assessment*
Murrumbidgee Irrigation				
Seepage	21[1]	42 - 63[3]	9-36	9-36
Deep percolation			74-101[2]	74-101[2]
Evaporation	62 (includes 40 GL evaporation from major storages and 22 GL from channels)	62		
Irrigation technology conversion				70 - 86
Total	***73***	***104 - 125***	***83 - 137***	***153-223***
Coleambally Irrigation				
Seepage	15[1]	15 - 30	4 - 16	4 - 16
Deep percolation			29 - 41[1]	29 - 41[1]
Evaporation	15[1]	15		
Irrigation technology conversion				15 - 74
Total	***30***	***30 - 45***	***33 - 57***	***48 - 131***
Rice Savings				
MIA				23 - 69 (1-3 ML/ha saving over 50% of area)
CIA				15 - 45 (1-3 ML/ha saving over 50% of area)

Table 28 - Accounted losses and water savings within the Murrumbidgee Valley diversion system.

Notes:

1 Within and near the jurisdiction of the irrigation corporations.
2 Including rice
3 42 GL for 67% of the total channel length and 63 GL for whole system

There may also be unaccounted losses from water removed from the system through river pumping and errors in water measurement due to, for example, the locally reported inaccuracies of Dethridge wheels of up to 14%.

Better irrigation practice not only increases water application efficiency and water productivity but has environmental benefits through:

- reduced surface runoff,
- reduced percolation to the watertable,
- reduced subsurface drainage,
- reduced export of salt and
- reduced chemical and nutrients in downstream waterways.

Figure 38 represents the current flow of water throughout the Murrumbidgee Irrigation supply area. The framework can be applied to any whole of system description. It identifies three water delivery efficiencies: conveyance; farm; and field efficiency and collectively terms these "irrigation efficiency". If there were no losses in the system these efficiencies would be 100%. This of course is not the case and instead there are off-farm conveyance losses and on farm distribution and application losses. Once the water is supplied to the root zone there are further opportunities to improve water use efficiency and water productivity. These are represented by the purple boxes on the right.

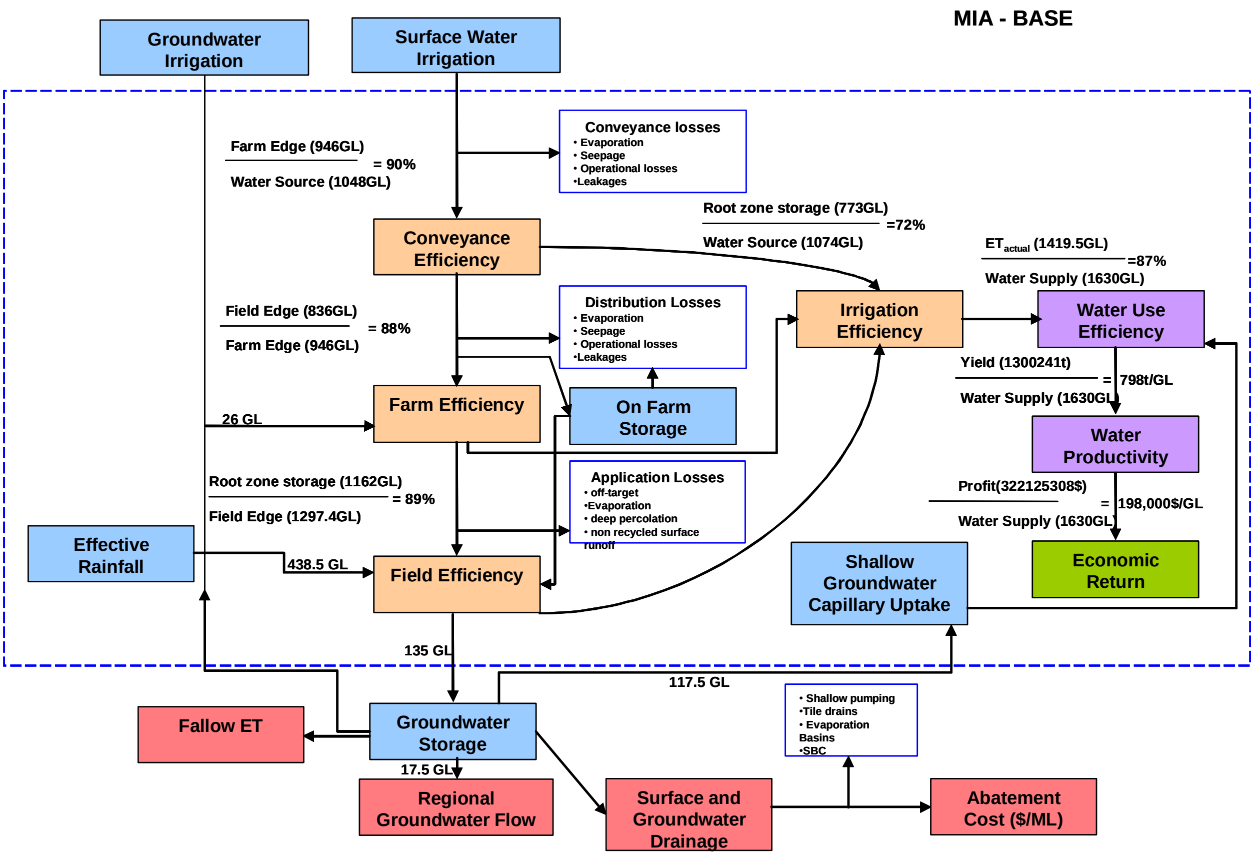


Figure 38 - Current whole-of-system description of water use efficiency for the MIA.

This study for the Pratt Water Initiative investigated the range of water savings options throughout the system and ranks these according to the potential savings of each option and the economic return in terms of ML saved for each dollar invested. Most of this work was conducted on large area farms of the Murrumbidgee Irrigation Area (MIA) and Coleambally Irrigation Area (CIA). Table 29 summarises the options and shows where each fits in the system.

Efficiency ratio		Water savings options
Irrigation efficiency	Conveyance efficiency	Identify and remediate seepage losses in supply channels
	Farm efficiency	Identify and remediate on farm seepage losses On farm storage and recycling of drainage water Covering storages
	Field efficiency	Laser levelling Flow monitoring Matching crop to soil and groundwater depth Conversion to pressurised system Soil moisture monitoring and irrigation scheduling
Water productivity		Optimising crop water requirements Optimising all agronomic inputs

Table 29 - Potential water saving options to improve water use efficiencies

6.6.3 Improving conveyance efficiency

Conveyance efficiency is the efficiency of delivery of water in the supply system, from source to farm. Conveyance losses can be caused by evaporation, seepage, leakage and operational losses but by far the greatest losses are to seepage. Seepage and leakage from water supply channels contribute substantially to ground water accessions. Leakage is the loss from physical breaks in the channels and can often be seen on the adjacent ground surface. Seepage is the loss from the walls and floor of a channel that is generally not apparent on the surrounding ground surface. Research was undertaken to identify, quantify and monitor the extent of channel seepage in the Murrumbidgee region and to recommend possible remediation methods.

Losses from supply channels

A survey using a combination of methods to measure seepage identified sites and quantified the extent of the losses. The data collected were also used to correlate the relationship between the methods.

Measurements were made over 700 km of channel which, when accounting for repeated measurement, comprised 500 net kilometres of loss detection. The measurements were taken from the larger channels in MIA, CIA and Lowbidgee.

Beds of the selected channels were surveyed using EM31 meters. These meters use electromagnetic induction to measure the average electrical conductivity of the soil from the surface to a depth of 6 metres. This average reading is known as “apparent conductivity”. The meter provides a quick way of gathering a large amount of data without any ground disturbance but is susceptible to interference from electrical or magnetic sources. Low conductivities indicate potential seepage sites.

Once the EM31 surveys were completed, maps were prepared from the imaging data using GPS references. These maps helped to identify the parts of channels where seepage was likely. Doppler flow meters were then used to measure inflow and outflow of particular reaches of channels. Large differences in readings between the start and end of the reach again indicated seepage losses.

Where seepage losses were identified Idaho seepage meters were installed at selected sites. A cylindrical bell is pushed into the bottom or side of a channel and is connected by tubing to a reservoir and gauge located on the water surface. As water seeps from the bell, the change in pressure in the reservoir is measured by the gauge.

All the data collected by the four methods above was used to “train” a model known as an artificial neural network (ANN) model. EM31 data, hydraulic conductivity, salinity and depth to watertable were used as inputs into the model with actual seepage results from the Idaho seepage meter provided as outputs. Once “trained”, the network can be used for forecasting but first it needed to be tested. When given only the input values the trained network predicted seepage values with a correlation coefficient of over 90%. Due to the highly non-linear relationship it is better to use the model to predict seepage rather than attempt to find a mathematical formula for the relationship.

Using ANN, the estimated total losses from 510 km of channels are 54 GL over 270 days, of which 42 GL can be attributed to seepage. At the same time, about 13 GL will be lost through evaporation for the measured length of the channels. All these losses could be saved if the channels were replaced with enclosed pipes.

The extent of estimated seepage from earthen channels in different irrigation water authorities was gathered by a survey of the authorities. The results of the survey are in a series of reports from ANCID (Open Channel Seepage and Control Reports (http://www.ancid.org.au/publications/index.html). These reports also identify methods of identification of leakage and seepage and the success of different amelioration and seepage control techniques.

Approximate economic evaluation of saving losses from channels

While potential water savings were identified for a significant length of major supply channel in the MIA the economic evaluation of the savings needs to be carefully done. The cheapest to most expensive methods of sealing channels are water sludge, rice hull, earth lining, membrane lining, lay flat pipe, concrete, reinforced concrete and then polyethylene.

While concrete is the longest lasting treatment it is the second most expensive and is not an economically feasible option at current water charges and technology costs. Of the least expensive sealing options the variable effectiveness is

1. Bentonite, 65-80% effective
2. Water sludge, 55% effective
3. Rice hull ash, 50-60% effective.

The volume and marginal capital costs of seepage savings from off-farm investment using these three methods are summarised in Figure 39 . This figure indicates that for bentonite lining there could be up to 20 GL of potential savings at a marginal cost of around $1500/ML to $2000/ML. Costs then rise, reaching $4000/ML at around 38GL reflecting the higher cost of bentonite.

In the case of alternative channel lining materials i.e. rice hull ash and water sludge there could be up to 20GL of potential savings at a marginal capital cost of around $400/ML to $500/ML. The marginal capital costs then increase reaching $600/ML at around 28GL for rice hull ash and at 32GL for water sludge.

Of these three, bentonite is the most effective option but also the most expensive option costing between $80,000 and $150,000 per km whereas water sludge and rice hull only cost between $15,000 and $25,000 per km based on an average wetted channel width of 37 m. Bentonite lining also requires a higher annual maintenance cost per annum.

There is always the option to “do-nothing” but this also has ongoing costs of channel and road maintenance and lost water.

The choice of option is dependant on the rate of seepage; the water price; the length of channel to be lined; the capacity of channel to be lined; and the financial discount rate that will determine the cost of financing the channel remediation.

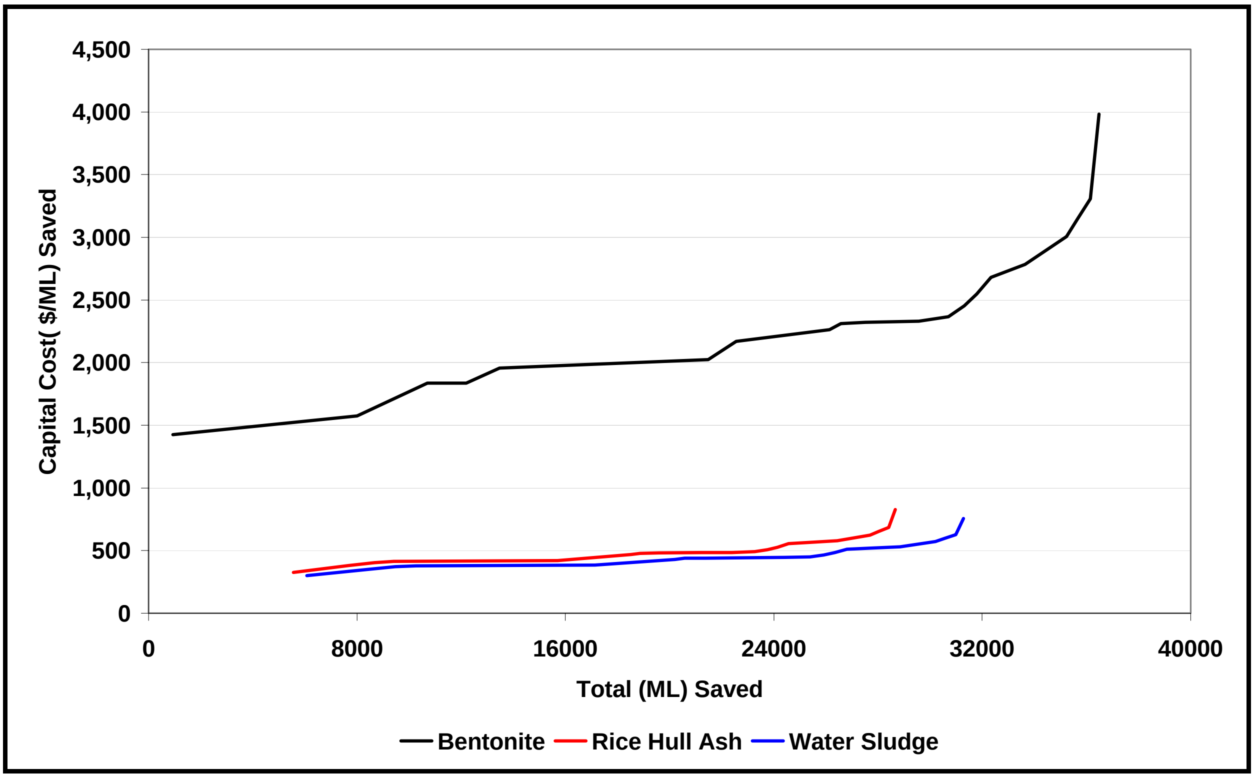


Figure 39 - Capital investment curves for saving seepage losses.

Key findings on improving conveyance efficiency in the MIA

- While channel losses are from leakage, seepage and evaporation, by far the greatest losses are from seepage.
- EM31 surveys are an important predictive tool in assessing seepage losses especially as a reconnaissance tool.
- Combining in situ seepage monitoring with EM31 surveys is effective in detailing the nature and extent of the seepage problem.
- Five hundred linear kilometres of channels in the Murrumbidgee Valley have been surveyed for potential losses. This work has already identified seepage areas that have been entered into current works programs and will provide an important benchmark for improvement in the future.
- Total losses from a given channel vary widely and can be from 1 to 30% of the water supplied.
- Seepage tends to occur in hotspots, for example, up to 9% of losses in one channel occurred in a single kilometre length.
- It is predicted that if seepage is not remediated, over 42 GL of water will be lost from 500 kilometres of channel in the MIA each year. All this water can potentially be

saved by lining or piping channels but at current water charging rates it may not be economically feasible to do so except in selected “hotspots”.

6.6.4 Improving application efficiency

The main assumptions for evaluating water saving options on an area wide basis for the MIA and the CIA and the detailed methodology of economic analysis of water saving options is described by Khan et al (2004a).

Approximate economic evaluation of cropping system savings

The areas of particular crops in for the MIA and CIA in 2000/01 were overlain on a crop and soils based GIS. It was then assumed that particular water savings on a per hectare basis would accrue as irrigation application moved from surface to sprinkler systems in broad acre crops and from surface systems to subsurface drip systems for vines, citrus and tomatoes. The main assumptions for assessing the water saving potential for the MIA are summarised in

Table 30 and for the CIA in Table 31.

Crop	Area* (ha)	Average water saving** Sprinkler (ML/ha)	Average water saving*** Drip (ML/ha)	Notes
Wheat	39215	0.4		
Barley	3034	0.6		Capital investment:
Maize	2924	0.6		
Soybean	2881	0.8		Lateral move: $1500/ha
Vines	13635		3.0	Central pivot,
Citrus	8700		2.0	towed: $2000/ha
Onions	1500	0.5		fixed : $2500/ha
Carrots	1500	0.8		Drip (SDI): $5000/ha
Tomatoes	1500		2.0	

Table 30 – Main assumptions for assessing water saving options for the MIA

* Khan et al (2004a and b), CICL (2003) Annual Environment Report, p. 48

** Developed from SWAP model simulations

*** Rendell McGuckian (2002). Irrigation Risk management Permanent Horticulture Kit Scope for Water Use Efficiency. Savings as a Source of Water to Meet Increased Environmental Flows – Independent Review: ACIL Tasman 2003.

Crop	Area* (ha)	Average water saving** Sprinkler (ML/ha)	Average water saving*** Drip (ML/ha)	Notes
Wheat	19484	0.4		Capital Investment:
Barley	4277	0.6		
Maize	3894	0.6		Lateral Move: $1500/ha
Soybean	1688	0.8		Central Pivot,
Vines	117		3.0	towed: $2000/ha
Tomatoes	96		2.0	fixed : $2500/ha
Sunflower	74	0.8		Drip (SDI): $5000/ha
Fababean	134	1.2		

Table 31 – Main assumptions for assessing water saving options for the CIA

* Khan et al (2004a and b), CICL (2003) Annual Environment Report, p. 48

** Developed from SWAP model simulations

*** Rendell McGuckian (2002) Irrigation Risk management Permanent Horticulture Kit Scope for Water Use Efficiency. Savings as a Source of Water to Meet Increased Environmental Flows – Independent Review: ACIL Tasman 2003

The main capital investment profile for different crops and overall investment curves for the MIA are given in Figure 40 and Figure 41 and for the CIA in Figure 42 and Figure 43. These investments range from less than $2000/ML saved to over $6000/ML saved.

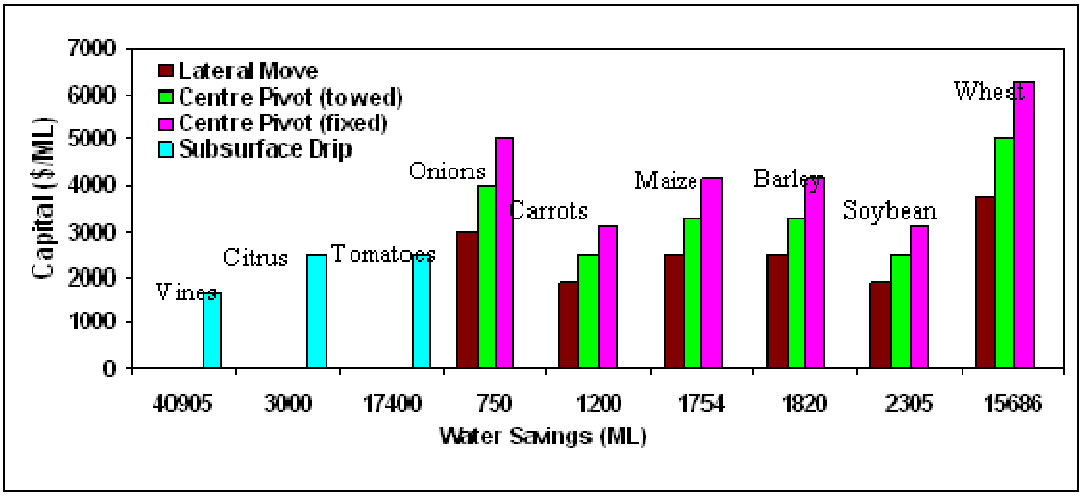


Figure 40 – Capital investment and potential water savings for different crops by high-tech irrigation technologies in MIA

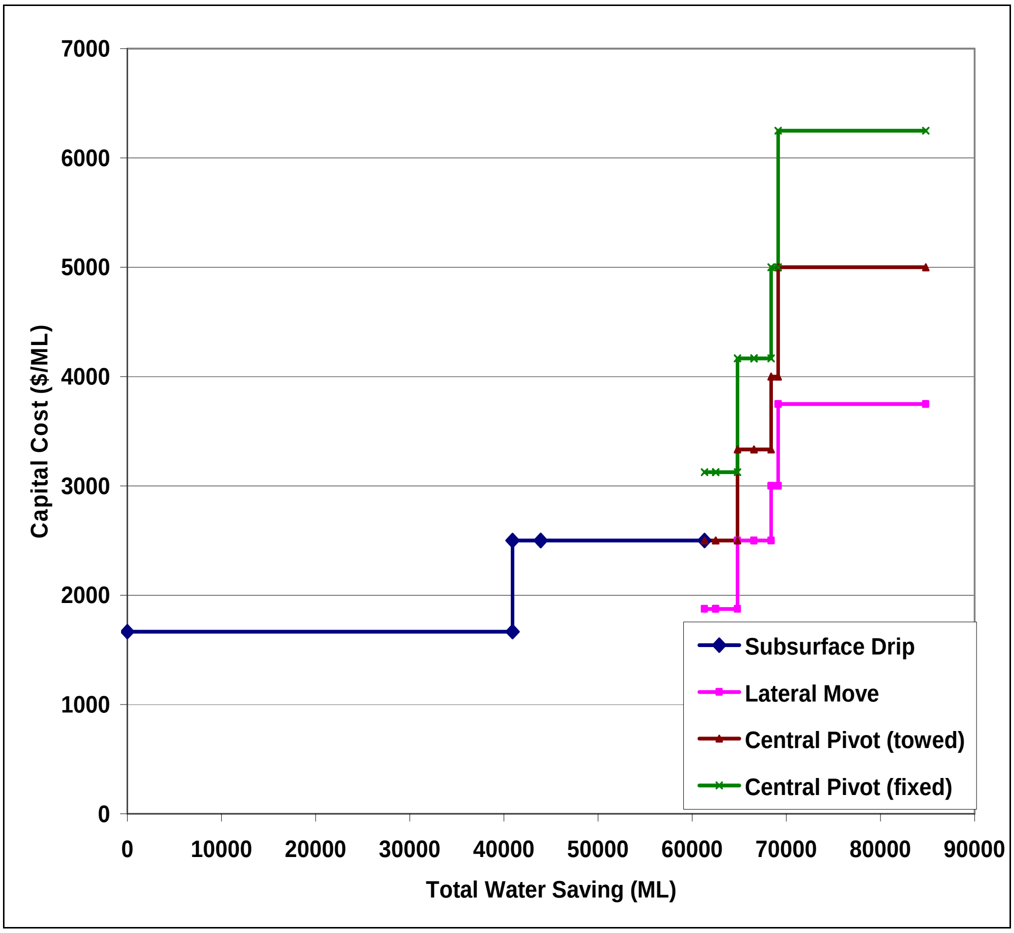


Figure 41 – Capital investment and total water savings by high-tech irrigation technologies in MIA

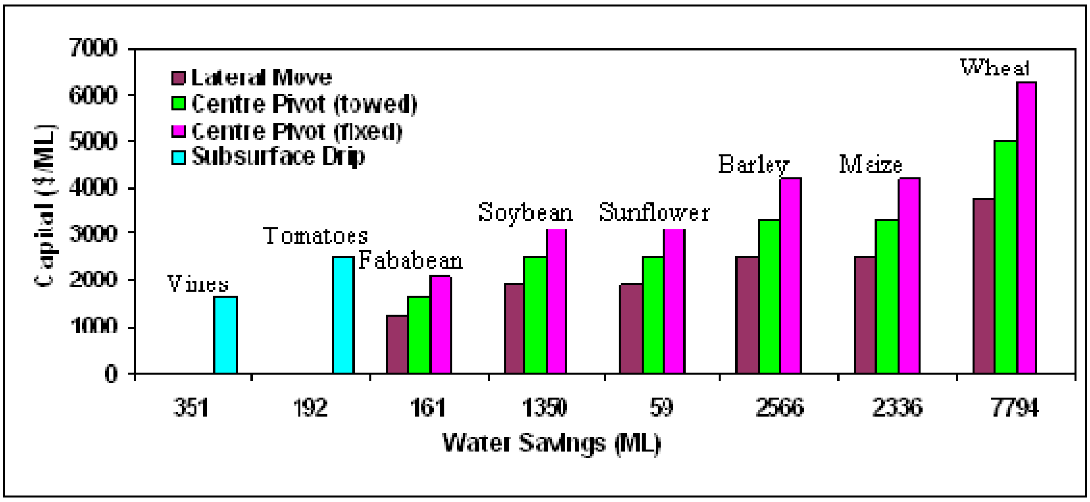


Figure 42 – Capital investment and potential water savings for different crops by high-tech irrigation technologies in CIA

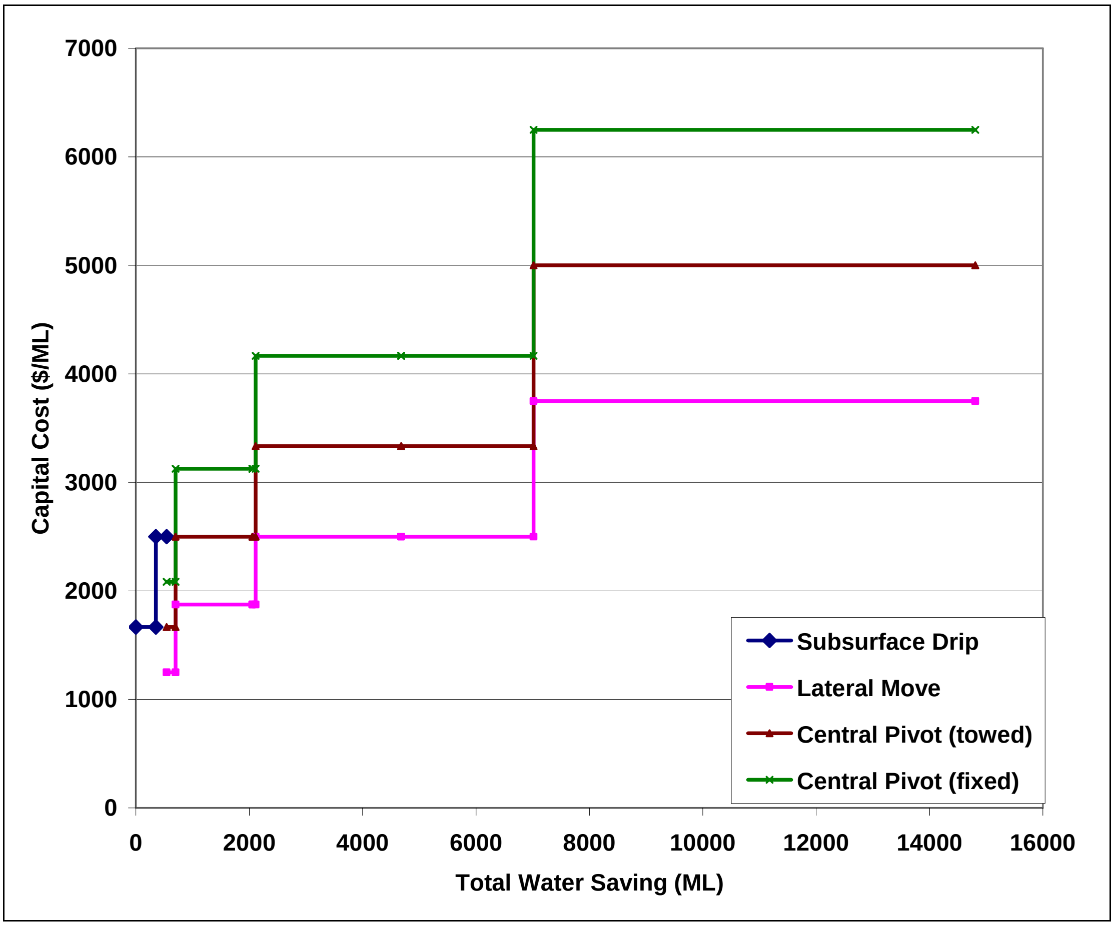


Figure 43 – Capital investment and total water savings by high-tech irrigation technologies in CIA

For the MIA, these data show that a saving of 60GL should be possible for a capital outlay of $150 million. To achieve a total saving of 85GL would require an expenditure of between $323 and $527 million. With an annual water diversion to the MIA of approximately 1,000GL the application efficiency improvement represents a 6% water saving that could be worth $60 million of water asset if traded at $1000 per ML. With a delivery infrastructure value in the Murrumbidgee region estimated at $397 million and an on farm infrastructure asset estimated at $1,086 million (Table 16) a further investment of $150 million (about 14% of current on farm asset value) seems reasonable. It is not clear how this could be implemented at the farm enterprise level and this is the subject of further investigation.

There is clear evidence from recent experiences in the Sunraysia and Riverland regions that major shifts towards more controlled irrigation systems occurs when there is synergistic investment with delivery system upgrades and on farm application systems. Three irrigation areas (Pomona, Coomealla and Curlwaa) converted from open channel supply systems to semi pressurised pipelines between 1989 and 2000. This resulted in a 58%, 28% and 34% reduction in the annual delivery volumes for the three areas. Immediately following the installation of these piped delivery systems there was a major shift in on farm irrigation application systems, for example in 1997 35% of the irrigation was furrow delivered with only 13% through drip systems. By 2003, the distribution was reversed, 13% by furrow, 36% by drip (Giddings, 2004). Similar responses have been recorded in other areas following conversion of distribution systems. Following conversion there is also clear evidence that drainage to underlying groundwater has reduced and shows up as increased depths to groundwater.

7 Tools to help manage irrigation and resources

7.1 Regional scale activities

All of the regions of interest in this study are within the Murray Darling Basin. As a result, they have been subject to the many and varied institutional changes that have been implemented through the Murray Darling Basin Commission and the three State governments. At the Murray-Darling Basin Commission level the development of the Salinity and Drainage Strategy signalled that land use, whether irrigated or rain fed, would need to be managed more carefully if salinity effects in the River Murray were to be controlled. This initial work has been followed by increasing focus on vegetation and biodiversity management and increasing recognition of natural and cultural history.

Early work by the States, for example, the drainage strategies for the most seriously affected areas of northern Victoria, has been replaced with more holistic planning intrinsic to regional Land and Water Management Plans. With the advent of Federal and State programs such as the National Heritage Trust (NHT) and, more recently, the National Action Plan for Salinity and Water Quality (NAP), the boundaries and responsibilities of local regions have been realigned. Currently, in NSW and Vic the regional natural resource management arrangements are being directed through Catchment Management Authorities (CMAs). In SA the responsible authorities are the newly formed Integrated Natural Resource Management (INRM) Boards. These Boards will provide the overview of works needed to bring about integrated planning for the use of land, water and vegetation resources within their region. Whether through a CMA or an INRM Board, the activities of irrigators in meeting the regional objectives for such things as the "end of valley" salt target or the preservation of specific vegetation will come under greater scrutiny. The next section provides some examples of activities that involve irrigators and that are designed to comply with regional natural resource management objectives.

7.2 What are the irrigators doing?

There is a network of agencies and organisations engaged in a wide range of activities that aim to improve the irrigation industry's performance, profitability and accountability. Increasingly we see a matrix of connections between irrigators, community groups, service industries, state and federal governments, research agencies, educational institutions, catchment groups and others to develop new and better technologies, techniques, and outcomes in general that also benefit the natural resource environment.

Individual companies are exceeding their own expectations by forming partnerships that enable them to achieve what may start out as modest goals. Thus far there are few examples of successful business arrangements that have made an explicit connection between their irrigation management practices and the river environment. One successful example is Banrock Station Wines (see Box 3) that has developed a market presence for its irrigated wines that are produced with high precision irrigation and connected to a tourist venture using regenerated wetlands on the river floodplain.

Pressure for change is coming from several quarters. In its submission to the "Alfred Deakin Irrigation Study" Feasibility Study, the First Mildura Irrigation Trust stated that "*wineries have put growers on notice that they will only take produce from growers with modern on farm watering systems, placing further pressure on existing suppliers of fruit in a competitive market. Further to this, demand for quality fruit, requires the supply of water by the authorities to be on an almost instantaneous basis.*

Regulated deficit irrigation, introduction by growers of sophisticated irrigation scheduling equipment, and the rapid conversion of old antiquated irrigation systems has increased the demand by growers for a worlds best practice supply authority."

Banrock Station

Banrock Station Wines, a BRL Hardy brand, has developed a successful cause marketing program for its wines, with proceeds from every bottle or cask sold going to Landcare Australia and Wetland Care Australia for wetland restoration projects around the country.

Banrock Station's commitment to wetlands began in the mid 90s when it worked with Wetland Care Australia to restore bushland, including 400 hectares of wetlands and floodplains on its own property.

The success of this project motivated the company to take the concept to the broader community and, in 1995, Banrock Station joined forces with Landcare Australia to support wetlands restoration projects throughout Australia. Donations generated by the sale of their wines have now exceeded $2 million.

Banrock Station now supports wetlands restoration and habitat preservation projects in other countries where it sells its wines including New Zealand, Sweden, Finland, the Netherlands, Canada, the United States and the United Kingdom.

Box 3 – Brief description of a commercial entity (Banrock Station) making a marketing connection to its improved multiple use of water.

The following information is from public documents and web sites and indicates the range of activities being undertaken throughout the Murray and Murrumbidgee Basins.

Coleambally Irrigation Cooperative Limited

- CICL has continued to monitor, every six months, vegetation condition at thirty seven sites that were selected for the 1998/99 Biodiversity Benchmarking Survey.
- In 2001, CICL was awarded an NHT grant to compare the management and Water Use Efficiency of buried drip with existing farming practices (sprinkler and furrow irrigation). The WUE site was developed with input from the community, Murrumbidgee Shire, CICL, NHT Greater Southern Energy, Patterson Pumps and CSIRO. The WUE site on the Demonstration Farm is believed to be the only site in Australia that allows comparison of crops grown under conventional furrow, sub-surface drip and overhead sprinkler, side-by-side, under exactly the same conditions.
- The organisation funds three PhD students and provides in-kind support for four others in a range of projects.

Source: *http://www.colyirr.com.au/Environment/index.asp*

Murray Irrigation Ltd

Land and Water Management Plan achievements in 2001/02 included:

- An investment of $47.6 million by shareholders on their farms to improve land and water management.
- More than 600 holdings with drainage recycling and reuse plans (since 1995).

- Over 170 shareholders have participated in formal irrigation training and property management planning. 379 farm families have participated in formal irrigation training.
- Landholders planted more than 350,000 trees in 2001/02, bringing the total since the plans began to almost 2.2 million, over 19,000 hectares.
- Over 3700 hectares of remnant vegetation have been fenced.
- There has been a general decline in high water table levels.

Current Activities

- Quantifying irrigation and rainfall runoff of irrigation farms.
- Further policy development of management options for sustainable irrigated agriculture.
- Develop a protocol for sustainable, commercially viable aquaculture using inland saline groundwater.
- Identification, measurement and remediation of open channel seepage.
- Review and evaluation of technical and economic feasibility of previously proposed on farm and regional management options in the Green Gully area.

Source: *MIL company profile brochure 2003 "What do we do?"*

Irrigators connected with the maintenance of wetlands

In the NSW Murray region a trial began in 2001 in which an independent community based wetlands rehabilitation group began to use water from the irrigation diversion to restore some wetland areas. As reported by Nias et al (2003) the group, New South Wales Wetlands Working Group Incorporated (MWWG),

"was to make water available to landholders within a large irrigation area for use on remnant wetland areas. The water to be provided was part of the water savings which the MWWG manages on behalf of the NSW government. Under the terms of privatization of Murray Irrigation Limited (MIL), it was required to achieve a program of water conservation measures through infrastructure improvements to reduce seepage losses and increase efficiency of supply. The NSW Department of Land and Water Conservation (DLWC) funded these works and a portion of the water savings (30,000 ML) resulting from these improvements was removed from the MIL bulk entitlement on 30 June 1999 and returned to the NSW Water Administration Ministerial Corporation. This volume is available for environmental purposes in the Murray Valley. In May 2001, the MSW Minister for Land and Water Conservation announced that the 30,000 ML of water savings was to be entrusted to the MWWG for a 3-year trial to support environmental improvements of wetlands. The flooding of wetlands on private land is one of a number of projects undertaken by the MWWG which has used the water for wetland restoration and enhancement".

The involvement of landholders together with monitoring of wetland condition before and after controlled water applications to remnant wetland areas has been shown to be successful. After an initial tentative start with just 10 landholder participants the involvement has grown to as many as 70 landholders in the last two years.

The summary provided by Nias et al (2003) is,

"The trial was a landmark project in the overall context of managing environmental flows. Using irrigation infrastructure, it delivered water to former wetland sites on private property and brought together a conservation group, private landholders, a major irrigation company and a government agency. It has demonstrated that positive change can happen, even in the face of initial uncertainty".

Murray Irrigation Limited and Goulburn-Murray Water have been heavily involved in the development of a management plan for the Barmah Millewa Forest, a wetland and forest area bordering the irrigation regions. The ecological and multi use value of the Forest area has been recognized and an environmental allocation of 100 to 150 GL of water is made available at certain times to provide ecological benefit to the area. Box 4 below provides a summary of the background to the trade between irrigation water diversion and environmental flow.

Case Study: Barmah Millewa Forest

The Barmah-Millewa Forest straddles the River Murray upstream of Echuca on the NSW-Victorian border, forming the largest contiguous stand of River Red Gums (*Eucalyptus camaldulensis*) in the world. The 70,000 hectare forest contains a diverse range of wetland environments, including Ramsar wetlands, swamps and marshes, rush lands, grasslands. lakes and billabongs, streams and red gum forest.

The ecology of the Barmah-Millewa Forest and wetlands is bound to the natural seasonal flow patterns of the River Murray. Flooding provides a breeding cue for wetland-dependent species such as frogs and water birds. It also provides the extra water required by River Red Gums to thrive in a semi-arid environment. Floodplain drying triggers wetland plants to set and shed their seed and is a crucial factor in nutrient cycling processes that govern floodplain productivity.

Inundation of the Barmah-Millewa Forest is dependent on flooding in the largely unregulated Ovens and Kiewa Rivers. As these rivers enter the Murray below Hume Dam, there is little capacity to store their floodwaters before reaching the constricted reach of the Murray through the Barmah-Millewa Forest. It is the two constricted sections (known as the Barmah and Millewa Chokes) and manipulation of numerous regulators on the river channel that allows water to be moved into different water management areas within the Forest.

The Forest annual operating plan sets out priorities for management of three types of flows:

1. The Forest's 100 GL environmental water allocation.
2. Supplementary flows, such as the September 2003 floods that typically originate in the Ovens during the natural seasonal flooding period, July-December.
3. Unseasonal flow events, which are usually rain rejection events during irrigation season, January-April, often resulting in adverse effects on forest ecology.

Environmental Water Allocation

In addition to the 100 GL allocated to the Forest in 1993, an extra 50 GL is available if certain conditions are reached, allowing a total of up to 150 GL per year for use. When the decision to use the environmental water allocation is made, the water is released from Hume Dam specifically to enhance watering for environmental purposes within the Forest.

Research and river modelling indicates that the best use of the environmental water allocation involves extending the duration of natural flooding, rather than creating large floods of short duration.

The environmental water allocation has been used twice to date, in 1998 and 2000-2001.

Source: Dept of Environment and Heritage
http://www.deh.gov.au/water/wetlands/publications/wa12/approach.html

Box 4 – Description of a major environmental site and its management that is connected with the irrigation areas of the NSW Murray and Loddon Campaspe.

Goulburn-Murray Water

- Developing environmental guidelines and operational procedures for control of dairy shed effluent, location of diesel tanks, and protection of high value environmental sites on Goulburn-Murray Water land.
- Management of sewerage at Goulburn-Murray Water reservoirs.
- Investigating a fish and mussel kill in the Broken Creek.
- Major focus on controlling environmental impacts arising from Goulburn-Murray Water project work and meeting associated regulatory requirements.
- Improving the performance of Goulburn-Murray Water sewerage works at Lake Eildon and Lake Eppalock.

Source: http://www.g-mwater.com.au/browse.asp?ContainerID=environmental_management

First Mildura Irrigation Trust

- Appointment of a Land and Water Management officer to progress on farm irrigation efficiency initiatives and work with key environmental groups in the Sunraysia area.
- Environmental and Water Savings Master plan (due November 2004). Future rehabilitation will reverse all existing diversions to the River Murray to inland structures.
- Representation on Sunraysia Drainage Coordination Group for management plan including Lake Hawthorn.
- Ongoing commitment to King's Billabong environmental management.
- Stronger controls introduced on planning applications seeking urban stormwater diversions to Trust drainage infrastructure.
- Continued reduction in drainage diversions to the River Murray.
- FMIT is preparing a biodiversity register.

Source: http://www.fmit.com.au

Lower Murray Irrigation in South Australia

Through the Land and Water Management Plan the group aims to:

- Eliminate dairy shed effluent return to any water body.
- Rehabilitate irrigation infrastructure to a current best practice system.
- Reduce water diversion from the river by 50%.
- Increase irrigation efficiency to 80%.
- Reduce drainage water volume by 60%.
- Reduce Total Nitrogen and Phosphorous returned to the River by 80%.
- Reduce Bacteria returned to the River by 80%.
- Ensure all new irrigation has no significant impact on the river.

Current Activities

- Laser levelling for better water distribution and reduced water diversions from the river.

- Installation of paddock inlets to reduce leakage of water.
- Upgrading of channels.
- Installation of demonstration meters to quantify water diversions.
- Reduced drainage water return to the river (= reduced N, P and Bacteria return).
- Installation of an improved water delivery site.
- Revegetation and Vegetation management, incentives and technical support provided by Mannum to Wellington LAP.

Source: Lower Murray Irrigation website http://www.lm.net.au/~lmiag/key_activity.htm

7.3 Irrigation management software tools

A recent compilation (Table 32) shows that there is an extensive range of software tools available at various levels to assist irrigators and water resource managers obtain, retain and use information for improved decision making. Uptake and use of these packages is highly variable and certainly not widespread across the regions or commodity groups. The continuing challenge is to incorporate these aids into user oriented, indispensable management aids.

Package	Owner	Lead developer	Does what?	Main application	Main benefit or strength	Main limitation
AgWISE™	Agrilink	David Sloane	Access process and interpret soil water and climate data	Irrigation and salt management	Schedule based on soil water monitoring	Depends on Agrilink server
Magpie	MEA	David Peacock	Access and report soil water and climate data	Irrigation planning and management	Easy access and display of weather data	Can only be used with MEA systems
IrrMAX v6	Sentek	Tim Waterhouse	Access, process and interpret soil water and climate data	Irrigation and salt management	Schedule based on soil water monitoring	Data could be misinterpreted
Micromet	Micromet	Jim Townsend	A daily water balance from climate data	Scheduling irrigation of urban parkland	Reduced wastage of urban water	Embedded in service from Micromet
IRES	PIRSA	Tony Adams	Store records in GIS database	Record keeping and WUE benchmarking	WUE improvement	ET_0 estimation and soil water monitoring
SWAGMAN - Destiny	CSIRO L&W	Emannual Xevi	Crop simulation, daily water and salt balance balances	Assess farm cropping options on $ and environment	Caters for salt water table and waterlogging	Professional use only. Input data is demanding
SWAGMAN - Farm	CSIRO L&W	Shahbaz Khan	Seasonal water and salt balance balances	Assess farm cropping options on $ and environment	Fast screening of crop/water options	Input data is demanding
MaizeMan	CSIRO L&W	Elizabeth Humphreys	Crop simulation, daily water and salt balance balances	Risk analysis and scheduling	Easy use of powerful crop simulation model	Input data is demanding
HydroLOGIC	CSIRO PI	Michael Bange	Crop simulation, daily water balance	Scheduling and increased WUE	Easy use of powerful crop simulation model	Probabilities are not reported
Aquatech	Aquatech	Jim Purcell	Spatial & temporal farm water balance	Whole farm water loss reduction	Improved recording and WUE	Requires professional support
DamEa$y	APSRU/ CSIRO	Shaun Lisson	Interactive database of biophysical and economic factors	Assess investments in on farm storage and/or irrigation	Rapid financial screening of dam and irrigation options	Limited to use in sugarcane in Bundaberg
WaterSupply	APSRU	Don Gaydon	Water and solute balances of water sources (dams, rivers, bores)	Assessing water supply options	Linked to powerful APSIM simulation environment	Users need experience with APSIM (not friendly)
Water-balance	CSIRO CSE	Geoff Inman-Bamber	A daily water balance from climate data	Irrigation scheduling for full irrigation	Fast and friendly	Limited to AWS network and sugarcane
Cane-optimiser	CSIRO CSE	Geoff Inman-Bamber	Runs APSIM from web interface	Irrigation scheduling for limited irrigation	Use of limited water at critical periods	Automatic but slow (40 min per paddock)
NoNameYet	NSW DPI	Helen Fairweather	Calculates Crop ET from web SILO data and FAO 56 equations	Irrigation scheduling for full irrigation	Seamless SILO access auto ETC calculation and graphics	Excel with internet macros is required

Table 32 – Recent listing of software tools used by irrigation researchers, advisors and consultants for irrigation water management. Adapted from Inmam-Bamber (2005).

7.4 Education and training in the regions

The irrigation industry, through various affiliated organisations has participated in several national projects that have identified skill requirements and developed training for the irrigation industry. The information base has come from National compilations such as "The Skills Audit of the Irrigation Industry" (Sloane Cooke and King, 1993), information source surveys (Cape 1993), the development of a set of Competency Standards (Australian Irrigation Training Project, 1996), overviews of University level irrigation courses (Graf et al 1996, Meacham and Arrow 1996, Meyer and Taylor 1998) and industry planning from the Irrigation Association of Australia (Carmichael 1996).

Within the regions identified in this study there is only one University that has a substantive presence and that identifies irrigation as a discipline area. Charles Sturt University with campuses at Wagga Wagga and Albury has specialist courses in irrigation at undergraduate and post graduate levels. It continues to develop a graduate certificate level course that enables people with industry experience to upgrade and broaden their qualifications. Other universities such as La Trobe (Wodonga and Mildura) have a presence but no specialty offerings for irrigation science. The major universities in Adelaide, Melbourne, Canberra and Sydney all have some subject areas of relevance to irrigation.

The former agricultural colleges at have either been absorbed into the city based universities Dookie (Vic), Roseworthy (SA),or have closed Yanco (NSW).

The need for vocational training and its connection to the formal competency based training programs was recognised through programs such as the Australian Irrigation Training Project (1996), which eventually lead to full recognition of the training standards within the irrigation industry. These standards are now being applied through skills development programs such as that being run by the Irrigation Association of Australia.

In each State the increasing involvement of TAFE institutions has provided increased opportunity for competency and technically based teaching programs tha tare designed for irrigation practitioners and some advisors. The most comprehensive development of this is through Mildura TAFE which has established a direct linkage between their course and the provision of irrigation farm assistance packages from the Victorian Government. This development follows earlier work that clearly recognised the link between irrigation research, policy, education, training and practice (Bryant et al 1993, Charlesworth and Meyer 1996). Further support for such linkage continues in the form of the "Riverlink" program. Riverlink is an informal joint venture between PIRVIC (Irymple), NSW Primary Indusries (Dareton), SARDI (Loxton) and CSIRO (Merbein) that aims to integrate programs and service delivery across the major horticultural centres in the Sunraysia-Riverland region. Riverlink benefits both industry and government agency staff through increased access and better use of resources. A Riverlink Council, with industry and agency representatives is the main forum for deciding policy issues, and to ensure that Riverlink effectively services the research, extension, and development needs of the regional horticultural industries. The role of the Council is to nurture, support, and strengthen the cooperative partnership between the four centres. (http://www.sardi.sa.gov.au/pages/key_links/riverlink.htm)

Within the regions there have been significant extension and learning opportunities particularly associated with the development of land and water management plans. One notable development was the formalised education program that the Coleambally Irrigation Area community commissioned (McCaffery 1998). These programs can be very effective locally but they need updating and maintaining to retain relevance. This maintenance requirement is often hard for regional groups to sustain and connections with and delivery by the formal education and training institutions is usually the only way to ensure longevity and continued impact.

8 Opportunities available for increased productivity and greater connection within the irrigated areas

While every effort has been made to obtain the latest information to include in this report, it is not possible to collate a complete set within the previous three to four years. This means that reports of this type will almost always be retrospective and in a rapidly changing global market environment, new or diminished opportunities will emerge and should change the snapshot-in-time conclusions that are reached. The following points are therefore more general rather than specific.

- Increased efficiency of irrigation water distribution is still possible. Identifying where the greatest gains can be made would be greatly aided by the gathering and analysis of more consistent and detailed statistical data describing where, what type and what performance irrigation enables. The Sunrise 21 activity (Sunrise 21 Inc 2005) in the Sunraysia is an excellent example of regionally based data gathering that will benefit irrigation and regional development.
- The standout statistics from this study point directly to the improved water productivity that has been gained by a few commodities over the last decades. Along with this, one cannot but be impressed at the continuing very large variability in farm enterprise performance in any commodity or regional survey. The essence from this is that improvement has been made and there is every indication that further significant improvement can be made.
- Improved irrigation application systems and their management are still possible and clearly warranted in many regions.
- Readjustment of where irrigation is practiced is certainly feasible and necessary – retirement of some areas in order to develop or make more intense existing areas must be actively pursued.
- Greater connection to the water supply through conservation action would signal serious intent by irrigators to play their part in redressing the balance of river flow and function and use of the water resource.
- The recommendations coming from the Pratt Water Study indicate an increased emphasis on making the connections between river flows and irrigation needs more apparent.
- Water being garnered for environmental flows to support the “icon” sites will need regional irrigator involvement to make this work to best effect.
- More effort is needed in looking for synergies between irrigation water management, the amounts and seasonality and water for the river and riverine environments.

9 Observations about the place and importance of irrigation in the Murray and Murrumbidgee

It is apparent that where significant change in irrigated practice has occurred as, for example, in the Riverland of SA and the Sunraysia region, there has been a combined effort involving policy, incentives, system delivery, on farm practice and commodity stimulus. Often, the expression of political will and leadership is needed to trigger a more concerted private sector shift. Indeed, public and private sector interaction is critical but first both parties need to be convinced that there is a better way and a more confident future.

A significant influence on the positioning of irrigation comes from looking at the regions e.g.

- For NSW Murray – the combined area diverts 1,900 GL for an irrigated revenue of $309 million;
- For Murrumbidgee (including Lowbidgee) – diversion is 1,750 GL for irrigated revenue of $479 million;
- For Riverland – diversion is 311 GL for irrigated revenue of $555m

The lesson from the Riverland rehabilitation process is that capital investment in supply delivery acted as a catalyst for considerable on farm investment. In the Riverina it seems quite clear that the selective application of delivery system improvement (channel rehabilitation, piping where economically sensible, increased flow at farm gate) along with controlled system (micro irrigation) introduction in higher value crops and improved surface irrigation layout would have considerable value.

One of the essential elements is that upgrading the delivery system is highly likely to have a synergistic effect on improved irrigation performance both through improved delivery and water control and also through an improved attitude and confidence in the future of irrigation. While there is some justification in improving irrigation delivery systems to achieve more controlled and accurate water delivery this is generally only economically viable with more capital and management intense commodities e.g. vines, fruit and vegetable production. However unless the delivery system can provide water on demand there will be an operational limit to the effectiveness of improved on farm application systems. Those irrigators that have direct access to the river, large on farm surface storage or on farm groundwater have an advantage in this respect.

One of the other major differences in the east and west regions of the Murray system is an attitude difference in the preparedness of the irrigators and their representatives to talk about rehabilitation and irrigated area retirement. The eastern areas are still highly defensive and the suggestion of adjusting and retiring the least suitable and poorest country is shunned or at best discussed in hushed tones. This is not so in the western areas where there is open discussion on the need to adjust and, if necessary, retire land and practice that is economically unviable or has high negative impact on the soil, water or groundwater resource base.

It is evident from the analysis of the different regions that the continued maintenance of the extensive irrigation and drainage channel networks of northern Victoria and Southern NSW will be an increasing financial burden. In the NSW Murray region for example, the production revenue base relative to the size of the distribution system means that the opportunity for greatly improved delivery services will be limited unless either the revenue base increases (perhaps by diversification of irrigated enterprises) or the region can attract very significant capital to fund significant upgrading. The dilemma is no less acute in northern Victoria, where the effects of low return pasture based grazing and areas of salinity affected production brings the continued viability of irrigation supply into question. In these cases the opportunity to trade the water entitlement asset is likely to assist rationalisation of the delivery system.

At a National and State level, a major motivator for regional development is the desirability of increasing the economic productivity from the use of resources, often expressed in terms of \$/ha or \$/ML. This makes rational sense when the resource, such as water becomes increasingly constrained i.e. generating greater economic per unit of the limited resource is a general good. While these measures are useful at this broad scale, they do not directly accord with the drivers of activity at the individual irrigated enterprise level. This study has illustrated that large returns are almost always accompanied by large capital and skill investment, although this does not necessarily lead directly to high profit - a major and critical determinant of enterprise viability. Irrigated farm businesses that are successful because they are profitable and operated by satisfied people come from the full spectrum of operations, from intense horticulture, large area cropping and dairying. Hence, many profitable irrigated enterprises do not have the same gross return per ha or per ML. Often, given the biophysical, market, infrastructure and skill conditions, the current use of resources is profitable and of significant local benefit. Whether, on balance, these resources could be used for alternate purposes with greater net benefit for society as a whole is much less clear.

Although it is useful to have broad scale measures with respect to the use of resources, such measures do not necessarily accord with the drivers at an individual enterprise level. Recognition of this does not diminish the reality that, within similar enterprises, performance is highly variable. Studies of this variability show that it is very strongly associated with variable management capability and that considerable improvement is always possible. Many of these improvements, generally aimed at increasing profit, or increasing ease of operation, will bring about improved water and land productivity, often by correlation rather than by causation. The existence of the highly variable enterprise performance means that there is considerable improvement that can be made in the use and productivity of the irrigated resource base. Identifying how to cost effectively achieve significant improvement remains a major challenge.

During the collation of information on water availability and the amounts being used for irrigation it is evident that great improvement in reporting and accounting for water in the Murrumbidgee and Murray systems has occurred over the last decade or so. This improved accounting, which has been strongly influenced by the state agencies through the Murray-Darling Basin Commission, has improved water management. However, as the case study in the Murrumbidgee Valley through the Pratt Water Study has shown, there is still considerable improvement to be made. It is also apparent that there has been improvement in the consistency of describing water and its management between the different jurisdictions. Further improvement is very important – there is still confusion at the most fundamental and most aggregated level. For example, it is not clear what the sum of the total water access entitlements is within regions or across the basins nor of the relationship between entitlement, annual allocation and actual diversion. Getting consistency of description, even down to the description of different access securities across states and regions, will greatly aid trade and irrigator behaviour – even at the risk of short term discomfort with changing names.

The imposition of the Murray-Darling Basin “Cap” from 1995 is designed to limit total extraction of water from the rivers to “1993/1994 levels of development”. For the Murrumbidgee and Murray systems the annual cap volume is approximately 8,734GL. Audit and compliance processes since 1995 have recorded the increased congruence of the volumes allocated for use, the amounts diverted and the target Cap volume. With water trading, intrastate temporary trade is by far the largest turnover with between 500 and 900 GL being traded annually since 1994/95. Interstate permanent trade, beginning in September 1998 in a limited area on the Murray below Nyah, in Victoria has been quite small (annually, less than 5 GL) with the net result since 1998/99 of 14 GL being traded into the Riverland and Lower Murray regions of SA.

In northern Victoria, the volume of water that has been permanently traded out of the three regions (Upper Murray, Goulburn Broken and Loddon Campaspe) for the period between

1990 and 2003 is 64 GL or 2% of the total annual diversion for these regions. During this time, the average price has ranged from $705/ML in a full allocation year to $1235/ML in the water short 2002/2003 season. There is some evidence that salinity affected areas in the Loddon Campaspe region have permanently traded more water than other regions. Presumably, irrigators realise the increasing asset value of the water entitlement relative to its productive value in salt affected areas. Temporary, within season transfers are much more common and have accounted for 7% of total deliveries in 1995/1996 to 30% in 2002/2003. The large trade in 2002/2003 is associated with the water shortage of that season. Prices for temporary transfer have ranged from $34/ML in 2000/2001 up to $364/ML in 2002/2003.

All the indications are that trade in water entitlements will increase. This will be aided by improved and more consistent definitions and recording of what water related product is being traded and any conditions attached. Thus far, contrary to early regional fears, there is no evidence that the water trade will cause wholesale, permanent loss of water from any one region. The prospect of significant money ($500 million) associated with the Living Murray process being used to fund infrastructure improvement and potentially buy water is likely to influence the water trade, at least in the short term. One concern, that significant water trade could activate “more” water than described in “the Cap” as it shifts from one water product description to another as it accompanies inter-state transfer should be addressed with rigorous water accounting and recognition of quantifiable system losses.

Appendices

Appendix 1: Development of Irrigation in the Murray and Murrumbidgee Basins

Upper Murrumbidgee River region in New South Wales

The two major storage dams servicing the Murrumbidgee Valley are the Burrinjuck Dam on the Murrumbidgee River and the Blowering Dam on the Tumut River. Major weirs along the Murrumbidgee include Berembed, Yanco, Gogeldrie, Hay, Maude, Balranald and Redbank.

The Snowy Mountains Scheme has a significant influence on flows in the Murrumbidgee River. Water is transferred through the scheme to generate electricity and most of the flow is discharged into the Murrumbidgee and Murray catchments. An average of 550 GL/year is diverted into the Murrumbidgee region via Blowering Dam, representing a major inter-basin transfer by reducing the flow in the south-flowing Snowy River and increasing the flow in the west–flowing Murrumbidgee River. This diversion will gradually be reduced as water is returned to the Snowy River in environmental flow initiatives.

Murrumbidgee Irrigation Area

Investigations into irrigation using water from the Murrumbidgee River began in the 1890s and were further stimulated by the devastating drought at the turn of the century. In 1906, the NSW Government approved construction of the Burrinjuck Dam and the Berembed Weir on the Murrumbidgee, facilitating the acquisition of land for farms and associated towns.

Work on Burrinjuck Dam began in 1907; Berembed Weir and 130 kilometres of the Main Canal were completed in 1911 and irrigation water was available to the newly proclaimed Murrumbidgee Irrigation Area (MIA) in 1912. This huge irrigation scheme was opened on 13 July, 1912 by bringing water from the Murrumbidgee River via a system of existing water courses and man made channels. By 1914, there were 677 farms in the MIA.

Burrinjuck Dam has been enlarged twice since 1929 (modifications were made between 1939 and 1956, and 1995-96) and now has a total capacity of 1,026,000 Megalitres. In 1968 Blowering Dam was built on the Tumut River with a capacity of 1,628,000 Megalitres and forms part of the Snowy Hydro-Electricity Scheme.

In 1999 the management of water distribution in the MIA changed from a NSW state government entity to Murrumbidgee Irrigation Limited, a public company whose customers are its shareholders. The company operates under licenses issued by the Department of Infrastructure, Planning and Natural Resources and the Environment Protection Authority.

Coleambally Irrigation Area

The township of Coleambally, established in 1968, was constructed to support a newly developed irrigation area for to use the water diverted westward from the Snowy Mountains Scheme. Coleambally was the last of the major government-sponsored irrigation developments in New South Wales.

In 1956, the Coleambally area was selected for development with the planned diversion of water from Gogeldrie Weir. The original proposal called for a total area of 190,000 ha, subdivided into 875 mixed farms of 180 ha, plus 200 horticultural farms of twenty hectares (Hallows and Thompson, c1996). The minimum size of mixed farms was increased in 1959 to 200 ha, of which at least 160 ha was to be irrigable. Full surface drainage works were also to be provided as part of the initial plan. By the end of 1969 there were 315 large areas and twenty two horticultural farms (Hallows and Thompson, c1996). Further development in the area ceased.

The original plan was to encourage mainly large wheat/sheep enterprises however, due to depressed rural conditions at the time, farmers were permitted to grow rice on a 'temporary' basis given that this was a successful crop in the MIA directly north of Coleambally. The impact of this strategy was quite dramatic, on both the range of crops grown within the region and the natural resource base. Rice was an easy crop to grow and more financially attractive than others but the resultant hydraulic loading on the land caused a rapid rise in the unconfined groundwater level that has since adversely affected much of the non-irrigated surrounds. Horticulture was relatively unsuccessful initially but there are recent efforts to increase this land use. Rice quickly became the major crop and by the 1980s, about 90% of water delivered was being used on rice.

In 1989, Coleambally Irrigation commenced privatisation. On 9th June 2000, government formally moved to transfer ownership and management of the state owned company, Coleambally Irrigation Limited, to the local irrigators. On 30th June 2000, the shareholders unanimously resolved to adopt a cooperative structure, to be known as *Coleambally Irrigation Co-operative Limited (CICL).* All 373 customers of CICL are now members of the Co-operative (CICL, 2001).

(Adapted from the Sinclair Knight Merz (2003) regional study and from http://www.colyirr.com.au/AboutCICL/index.asp)

The Murray Valley of NSW

Before 1850, settlement of the Murray Region was restricted to lands adjacent to the main water courses, but new land legislation and the discovery of groundwater suitable for stock led to gradual occupation of the country remote from the water courses. Land use at that time was primarily wheat and wool production on large holdings.

As far back as the 1860s, interstate conferences were held to consider development of the Murray River for navigation and irrigation, but it took fifty five more years to ratify the River Murray Water Agreement of 1915. The works to be carried out consisted of two large storages, one above Albury, and the other at Lake Victoria, together with twenty six weirs and locks on the Murray River between Echuca and the ocean. As a result of decreasing river traffic following road and train competition, the number of weirs and locks was reduced to thirteen.

Construction of the Hume Dam near Albury commenced in the 1920s, with weirs and locks built concurrently. The Hume Dam made large controlled flows of water in the Murray River available. The NSW Water Conservation and Irrigation Commission investigated the feasibility of irrigation development to provide some stability for land settlement in the region. Construction commenced in 1933 and by 1935 water was available to the first holdings in the Wakool Irrigation District. The first major construction was a diversion weir on the Edward River, twenty four kilometres downstream of Deniliquin. Detailed topographic surveys were carried out over vast areas including the present irrigation districts, and areas covered by the Corurgan and Moira schemes. In 1935, construction of the Mulwala Canal began and by 1939, it was completed as far as Finley.

(Adapted from http://www.murrayirrigation.com.au/content.php?p=19&s=mil)

Licensing of water use in NSW is controlled by the 1912 Water Act, the Water Management Act 2000, State Water Management Outcomes Plan and more recently Water Sharing Plans developed in different river catchments (NSW Department of Sustainable Natural Resources 2003). The Water Conservation and Irrigation Commission was formed in 1913 to control all related projects. Drought prompted The River Murray Water Agreement to be drawn up in

1915 by state and federal governments, and the River Murray Commission was established in 1917 to implement the Agreement.

The Wakool Irrigation District was established in 1932, followed by Deniboota and Denimein Irrigation Districts in 1938, Berriquin Irrigation District in 1939 and Tullakool Irrigation Area in 1942. Water usage in NSW grew rapidly after World War II. Since the 1960s, there has been a shift away from traditional farming of sheep and wheat in NSW to higher usage (ML/ha) production such as rice growing.

In response to the recognised over-allocation of the Murray Darling basin, the Murray-Darling Basin Commission Cap was put in place in 1995, limiting water use across the basin to 1993/94 levels of development. A brief chronology of significant events that affected the irrigation of the NSW Murray region is given in Box 5 below.

Year	*Event*
1912	*Water Act (Boughton, 1999)*
1913	*Water Conservation and Irrigation Commission*
1915	*River Murray Water Agreement (Boughton, 1999)*
1917	*River Murray Commission established*
1919-1936	*Hume Dam construction (Boughton, 1999)*
1932	*Wakool Irrigation District (Boughton, 1999)*
1938	*Deniboota Irrigation District (Boughton, 1999)*
1938	*Denimein Irrigation District (Boughton, 1999)*
1939	*Yarrawonga Weir completed (Boughton, 1999)*
1939	*Berriquin Irrigation District (Boughton, 1999)*
1942	*Tullakool (Boughton, 1999)*
1949-1974	*Snowy Mountains Hydro-Electric Scheme*
1961	*Hume Dam enlargement (Fluvial Systems, 2002)*
1979	*Dartmouth Dam completed (Boughton, 1999)*
1986	*Water Administration Act*
1992	*Intergovernmental Agreement on the Environment*
1992	*Murray-Darling Basin Agreement*
1992	*Murray-Darling Basin Commission Salinity and Drainage Strategy*
1994	*Water Resource Policy (COAG)*
1995	*Murray-Darling Basin Commission Cap*
1997	*Completion of privatisation/corporatisation of irrigation areas/districts in NSW*
2000	*New Water Act in NSW*
2004	*National Water Initiative*

Box 5 - Selected chronology of events for NSW Murray regions

The privatisation, or corporatisation, of all irrigation areas and districts in NSW had occurred by June 1997 to encourage local irrigator management and control.

Land and water management plans were introduced to encourage greater community involvement in ensuring sustainable use of resources.

Northern Victoria

The Victorian Government became involved in irrigation following the 1877-1881 drought that severely affected northern plains farmers who had settled the area in the good years between 1870 and 1875 (Hallows and Thompson, c1996). Recognising that without supplementary water supply and irrigation, the northern region of Victoria could not be successfully occupied, a report was commissioned to investigate the best means of conserving water (Goulburn-Murray Water, 2003).

Two resultant reports suggested that the waters of each of the rivers in the regions be used as far as possible within their own basins, conserving the water in the streams, creeks and watercourses by constructing weirs, dams and natural reservoirs for use during the dry summer periods (Goulburn-Murray Water, 2003). These reports led to the Water Conservation Act of 1881 (amended in 1883). This was the first Victorian legislation in which express provision was made for the construction of irrigation works.

In 1882, the Echuca and Waranga Shires discussed a proposal to irrigate land from the Goulburn River (Hallows and Thompson, c1996). Construction works were started immediately and included a channel from the Goulburn River to the “natural reservoir”, the Waranga Basin (Hallows and Thompson, c1996). However, the state government supported work on a major diversion weir and the Basin had to wait until the period 1887 to 1902.

In 1886, the Australian Parliament passed an Act that marked the beginning of a new era in water supply legislation (Goulburn-Murray Water, 2003). This revolutionary Act gave the Crown the right to use water in any stream, lake or swamp, and provided that no riparian rights (previously granted under English common law) could be established in the future which might prevent the use of water for irrigation. The Act also authorised the construction of national works by the State and enabled elected Trusts to carry out water supply projects with money advanced by the Government (Goulburn-Murray Water, 2003).

By 1900, Victoria had nearly ninety Irrigation and Waterworks Trusts, many of which failed due to lack of engineering and agricultural knowledge rather than lack of enthusiasm (Goulburn-Murray Water, 2003). The Water Act of 1905 abolished all Trusts (except the First Mildura Irrigation Trust) and gave control of rural water supplies to a newly created *State Rivers and Water Supply Commission of Victoria*.

There were great fluctuations in the rate of expansion of irrigation in the first half of the 20th Century. Growth ceased or slowed markedly during the Great Depression and the two World Wars, and accelerated with the introduction of closer settlement policies following both World Wars (Hallows and Thompson, c1996). Large storages and channels were constructed, opening new tracts of land for irrigation and enabling the expansion of dairying, vines and fruit enterprises.

The abundance of natural streams and lakes within the region facilitated the development over the years of a complex system involving many regulators and weirs on permanent and ephemeral natural streams, the use of swamps and lakes as in-system storages and various pumping installations, flumes and syphons (Hallows and Thompson, c1996). Wet periods caused waterlogging and the death of many trees, and led to the commencement of formal comprehensive drainage systems.

The *Rural Water Commission,* which succeeded the *State Rivers and Water Supply Commission* in 1984 operated and maintained most of the State's water supply system including watercourses and storages (Hallows and Thompson, c1996). In 1992, the *Rural Water Corporation* was formed, with fewer regions and greater powers given to Regional Management Boards (Goulburn-Murray Water, 2003). In July 1994, five Rural Water Authorities were created in Victoria from the former regions of the *Rural Water Corporation*, with Goulburn-Murray Water being by far the largest (Goulburn-Murray Water, 2003).

Goulburn-Murray Water manages water storage, delivery and drainage systems, covering an area of 68,000 km^2 involving 70% of Victoria's stored water. It operates on a cost recovery basis and provides for the ongoing refurbishment of infrastructure of the system.

(Adapted from the Sinclair Knight Merz regional study (2003) and from http://www.g-mwater.com.au/browse.asp?ContainerID=history_of_irrigation)

Sunraysia, Riverland and South Australian Lower Murray

In addition to water for irrigation, the Murray River has been an important feature of industry and transport and, more recently, tourism. From the 1850s, paddle steamers carried goods to the Murray settlements and wool and wheat from them, until faster and more efficient forms of transport, such as railways, superseded them. Recent research has indicated Murray River tourism is both a significant and growing component of the regional economy (Burgan 2002).

According to "The Wakefield Companion to SA History" (Prest et al. 2001),

> "Irrigation from the **River Murray** was commenced in 1881 by Governor **William Jervois** who had reclaimed a swampy area near Murray Bridge. The government reclaimed further swamps for dairying at Mobilong, Monteith and Mypolonga during 1905–10. Meanwhile, the **Chaffey brothers** had been licensed in 1887 to occupy 30,000 acres (12,000 hectares) for irrigated horticulture near what became Renmark but fell into financial difficulties. Consequently, the Renmark Irrigation Trust was established in 1893. In a further development in the early 1890s to alleviate distress, the government allocated land and funds for irrigated village settlements at Ramco, Waikerie, Holder, Kingston, Moorook, Pyap, New Era and Lyrup, with settlers responsible for interest and ultimate repayment of capital. Most quickly failed. Only Lyrup survived as a village settlement beyond 1913."

The colonial governments of South Australia at Renmark and Victoria at Mildura actively supported irrigation as a tool to encourage increased settlement of inland areas, favouring small property sizes (Murray-Darling Basin Commission 2003a).

Soldier settlement after both World War I (Berri, Cadell and Waikerie in South Australia) and World War II (Cooltong and Loxton in South Australia and Robinvale in Victoria) encouraged further irrigation development, again often with small farm sizes.

<u>Sunraysia</u>

The development of the Menindee Lakes into a storage for irrigation of the Lower Darling region commenced in 1949 and finished in 1960 (Boughton 1999). Surveys for the Coomealla Irrigation Area began in 1923, and subsurface drainage was installed in 1937 due to high watertables associated with earlier irrigation activity (Moore, 1998, 2000). Private diverters, pumping water directly from rivers and groundwater, have been the source of most of the expansion of irrigation areas since the 1960s.

(Adapted from the BTRE (2003) report)

<u>Riverland in South Australia</u>

The first Australian irrigation settlement was established at Renmark in 1887 by the Chaffey brothers. The enterprise initially involved 12,000 ha of land adjacent to the River, irrigated using pumps and earthen channels, and now forms part of the privately operated Renmark Irrigation Trust.

Development continued in 1894 with the establishment of eleven communal village settlements at 32 km intervals along the river. These settlements could not achieve selfsufficiency and most were disbanded within ten years. However, the Lyrup Village Irrigation Area (between Berri and Renmark) still survives and other settlements have since formed the basis of private and government irrigation areas (Waikerie, Ramco and Moorook).

Additional irrigation settlements, both above the river trench (often called highland irrigated areas) and on reclaimed areas of the floodplain, were established for returned soldiers after World War I (Berri, Cadell, Cobdogla and Ral Ral) and World War II (Cooltong, Loveday and Loxton). From the late 1950s, these schemes were followed by the private irrigation schemes of Golden Heights, Sunlands and Ramco Heights, near Waikerie, and at other locations, including Sherwood, Media, Swan Reach and Greenways (Nildottie).

Most of the irrigation in the highland areas is located on Mallee dunes and requires pumps to lift the water to significant levels above the river.

Rising salinity of the Murray was first recognised in the 1950s and came to a head during the dry 1967/68 season, when high salinities and low river flows resulted in significant crop damage. The South Australian Government responded by declaring a moratorium on irrigation along the river, requiring the licensing and allocation of irrigation water. Also, during this time construction of piped distribution systems began to replace open channels enabling increased efficiency and productivity. At Berri the area irrigated by sprinkler and drip systems more than doubled in the eight years following rehabilitation of the water supply system. All former State Government Highland Irrigation Districts (GHID) have now been converted to piped distribution systems. The recent end of this rehabilitation program was linked to the transfer of all former GHIDs to private ownership from mid-1997. Nine of the former GHIDs are managed by Central Irrigation Trust (CIT).

Significant salt interception scheme infrastructure has been constructed to mitigate the displacement of salt towards the river. Comprehensive drainage schemes have been constructed since 1957 to combat rising groundwater levels (Boughton, 1999), however, the saline drainage was disposed to floodplain lagoons and is likely to have contributed salt to the river at least during times of flood. The Noora Drainage Disposal Scheme was constructed in the early 1980s and drainage water was diverted to salt pans located far from the river. In addition, groundwater interception schemes operate adjacent to the river at Rufus River, Waikerie and Woolpunda.

<u>Lower Murray Swamps</u>

William Jervois commenced irrigation on a reclaimed swamp area near Murray Bridge in 1881. Later activity at Woods Point Estate, south of Mannum, permanently reclaimed swamp areas for flood irrigation in the early 1900s using levy banks and drainage channels. Today, virtually all of the major floodplain flats have been reclaimed south of Mannum (Boughton, 1999), mostly for irrigated dairy pastures. Since the construction of the barrages near the Murray Mouth, the level of the reclaimed irrigation areas has been between 1.0 to 1.5 m below river levels (Primary Industries and Resources South Australia, 2001). Some areas adjoining reclaimed land are used for intensive irrigation of horticulture, particularly at Mypolonga.

It is worth noting that in recent years some of these “reclaimed” swamp areas are being abandoned through a combination of increased salinity, limited productivity for dairy pastures, increasing controls on drainage returns to the river and because water entitlements are being sold and traded out to other users including urban water suppliers.

Appendix 2: Irrigation application systems used on farm in the Murray and Murrumbidgee Basins

Provided by E.W. Christen, J.W. Hornbuckle and J.E. Ayars

Surface irrigation

These are gravity systems where water flows from the higher end of the field to the lower. The more common types are called furrow, contour bay and border check.

For furrow irrigation, the field is divided into a number of small channels (furrows) with regular cross sections. Furrows have raised beds or hills in between, with the crop planted on these hills or beds. Water is supplied to the upstream end of the furrow and “advances” down the furrow and infiltrates through the wetted perimeter, moving vertically and laterally Once the water supplying the furrow is stopped (“cut-off”), the water “recedes” down the furrow. These same principles apply to border check irrigation, where water is applied to large bays ~20-80m wide which have no furrows. Efficient furrow and border check irrigation will depend upon soil type, slope, layout and the crop to be grown. An important feature for furrow-irrigated soils is that the water is able to infiltrate the bed or hill and redistribute to the surface. This is essential for seed germination and crop establishment.

The speed and duration of the advance and recession phases of water supply in furrow and border check irrigation determine the uniformity of water application. Under ideal conditions, the advance and recession curves with respect to distance and time in the furrow or bay should run in parallel to ensure that the infiltration time is the same over the entire furrow length. If this is achieved, a uniform amount of water would be applied to the soil at the head of the furrow or bay and at the end of the furrow or bay.

Distribution uniformity with surface irrigation

The main problems associated with surface irrigation are the non-uniformity of water application and over-irrigation (more water applied than can be held by the soil. Smith et al. 1983). Design and management of surface irrigation systems are generally poor, causing inefficient irrigation and water wastage. These problems are exacerbated on light textured (sandy) soils and reduced on heavy textured (clay) soils. Lighter soils, having more rapid infiltration, need to be on steeper slopes with shorter lengths of furrows or bays (runs). The uniformity of water application in surface irrigation systems is influenced by

- inflow rate;
- cut-off time;
- furrow length and slope;
- furrow geometry;
- soil infiltration characteristics; and
- hydraulic resistance.

To design and manage efficient surface irrigation systems, considerable understanding is required of the interaction between soil conditions at the site, water supply and cropping. In general terms, it is more difficult to design and manage furrow irrigation compared with sprinkler or drip systems. In practice, furrow irrigation has mostly been designed on ‘best bet’ or local knowledge. Greatly improved design tools are now available to guide both design and management for efficient surface irrigation.

Sprinkler irrigation

There is a large range of sprinkler equipment that can be tailored to particular crops and soils. The application rate can be matched to the soil infiltration rate, with good management, to minimise deep percolation. Soils with very low intake rates (less than 3 mm/hr final intake rate), are prone to runoff and need special measures to increase intake or provide uniform surface ponding to prevent runoff (Burt and Styles, 1999). Sprinkler irrigation is excellent for germination and crop establishment since small amounts of water can be applied frequently, often with low labour requirement. Other agronomic advantages are control of wind erosion and incorporation/activation of herbicides. With good design, it is suitable for undulating and steep terrain, although great care is needed to avoid surface run off.

Disadvantages with sprinkler irrigation include the high capital and operating costs, the risk of crop damage from foliar application of saline or reclaimed water and increased risk of plant fungal disease Difficulties with sprinkler irrigation usually occur in two forms, excessive ponding and run off due to a mismatch in application rate and soil infiltration (most frequently a problem with travelling sprinkler systems) and excessive deep percolation (usually due to poor irrigation scheduling and poor distribution uniformity). These problems can be avoided with adequate soil investigations beforehand and appropriate design, proper system maintenance, and good irrigation scheduling techniques.

Types of sprinkler systems

Sprinkler irrigation is commonly used in horticultural irrigation and for some fodder and grain crops. Field crop sprinkler systems are usually overhead spray systems that apply the water over the whole plant and ground area. For perennial horticultural tree crops, older overhead sprinkler systems wet the whole area. Most recent systems operate as under tree micro sprinkler systems that wet under the trees, but not the inter-row areas.

Systems for field crops include fixed (solid set), hand move (single lines of a solid set system that are moved across the field), and travelling irrigators.

A solid set system is a system with mainline and laterals that remain in place all of the growing season. It is well suited to irrigating crops that need light, frequent irrigations. These systems have high capital cost but require very little labour for irrigation. The fixed pipes and risers are obstacles to farming operations.

The hand-move system generally consists of a portable main line that is in place for the growing season and one or two laterals. The laterals are moved across the field for each irrigation cycle. This system reduces the capital cost but dramatically increases labour costs. These systems are designed so the average application rate is less than the soil infiltration rate to avoid run off.

Travelling irrigators can be moveable booms and guns, centre pivots and linear moves. Travelling booms and guns are high volume, high pressure systems where the application rate is determined by the sprinkler design, water pressure, and travel speed. Because of large droplet size and high application rates these are best suited to light soils having high infiltration rates and crops that can sustain heavy wetting and have good ground cover. These systems generally have poor uniformity of application (Burt and Styles,1999).

Centre pivot and linear move systems carry a row of sprinklers either around in a circle (centre pivot) or across a rectangle of land (linear move). With centre pivot systems the outer end travels much faster than at the circle centre and so instantaneous water application rates are much higher at the end. With both these systems the application rate can be 60-250 mm/h. This is much higher than the infiltration rate of most soils, so potential runoff is decreased by increasing the advance travel speed and having more frequent smaller irrigations. With both these systems there has been a trend to use nozzles and spray plates on drop tubes, so that the water is closer to soil surface. These are alternative emission devices that run at lower pressure and have smaller droplet sizes (Burt and Styles, 1999). This reduces the application rate and preserves soil structure. These systems used on flat ground can pond water into furrows without runoff. Using these systems also minimizes evaporation and negates the impact of wind.

Distribution uniformity with sprinkler irrigation

With sprinkler systems the uniformity of water application depends upon the sprinkler type, its spacing in the row and spacing between rows. The depth of water applied is usually greater near the sprinkler and decreases with distance from the sprinkler. Uniformity of application is achieved by placing sprinklers such that the wetting patterns overlap, usually about 60-80%. In design, the engineer will consider the nozzle pressure, discharge rate, diameter, and water distribution pattern to obtain acceptable uniformity. Poor distribution uniformity will occur around edges of fields or in odd shaped fields where sprinkler overlap cannot be maintained. With under-tree sprinklers each line of sprinklers is an individual source and as such only the spacing along the line is critical and not the row to row spacing.

Other sources of non-uniformity are pressure drop along the sprinkler line, incorrect system pressure and wind. System pressures higher than recommended will cause the water to break up into finer drops. This will cause more water to fall near the sprinkler, increase susceptibility to wind drift, and increase evaporative losses. System pressures lower than recommended will reduce the amount of overlap between sprinklers and result in larger water droplets and hence a greater water application will occur at the periphery of the wetting pattern.

Drip irrigation

Drip is a technologically advanced method of irrigation that can apply water evenly to plants right across a paddock (see text Burt et al, 1995). To achieve this, water is pumped around the paddock in pipes to emission points close to the plant root zone. The piping, pump and associated hardware are expensive, upwards of $3000/ha, making the system highly capital intensive. It is this combination of technology and high capital cost that makes drip irrigation a potentially risky investment. In order for a drip irrigation scheme to be successful it must be well designed, properly installed and well managed.

Drip irrigation of permanent horticultural plantings is well established and its use in row crops is gradually increasing as the key components for success are converging;

- systems designed to a high standard specifically for Australian farming conditions,
- cost/ha declining as more equipment is made in Australia and costs worldwide become more competitive,
- management skills increasing, and
- well developed business plans in place to ensure return on investment.

Drip irrigation requires high levels of management skill and financial investment and is thus a transition that can best be made when the crops to be grown with drip have already been successfully grown with furrow irrigation, ie high level agronomy, marketing and financial skills are already developed.

Drip irrigation is also likely to be the most suitable form of irrigation for use with reclaimed or saline water for two important reasons. First, it limits contact of the reclaimed or saline water with the plants and workers in the fields. Second, it provides the best control over the application of irrigation water. The high level of control is important as it leads to high yield of vegetable crops, e.g. 20-30 t/ML for processing tomatoes, compared with 10-20 t/ML for furrow irrigated crops, (Hickey et al., 2001). It also leads to reduced environmental impacts (ie. no irrigation runoff and little rainfall run off and little drainage past the root zone, if well managed).

The principles of drip irrigation

The overriding principle of drip irrigation, which sets it apart from all other irrigation systems is, “irrigation is closely matched to the crop water use on a daily (or sub-daily) basis”. Below are the characteristics of drip systems that help achieve this.

- Water is applied frequently at low application rates. Drip irrigation can only apply water at low rates e.g. 14 mm/day. This means that drip systems are operated frequently and are run for long time periods (sets). These features are a constraint to irrigation in that large soil water deficits cannot be replaced quickly. However, management of drip irrigation to prevent large soil water deficits from occurring creates a root environment where plant water uptake is near potential rates.
- Water is applied uniformly to all plants. The ability to apply practically the same amount of water to each plant in a paddock is a unique feature of drip irrigation.
- Water is applied directly to the plant root zone. This also makes drip irrigation unique from all other types of irrigation systems. With drip irrigation only the root zone of the plant should be wetted. Thus, in the horizontal plane for row crops only the hill or bed is wetted not the furrow area and in the vertical plane the water is kept in the root zone by not allowing drainage below the root zone. Thus, in most cases up to 25% of the paddock area is kept dry.

When the above principles are considered it is not surprising that world record crops of tomatoes have been grown with drip irrigation and large yield increases are often found when drip irrigated crops are compared with furrow irrigation. In some cases, yields under drip irrigated crops are the same as, or even less than comparable furrow irrigated crops. This can be due to poor system design or poor system management. It will necessarily take a few seasons of experience to learn the best management for any new irrigation system. Drip irrigation is particularly demanding to manage.

Distribution uniformity with drip irrigation

One of the key benefits of drip irrigation is high water application uniformity. If every plant in the paddock were to receive exactly the same amount of water then the system uniformity would be 100%. No irrigation system (even drip) can actually achieve this - some plants will always get more than others. With drip irrigation the application uniformity depends upon the variation in emitter flow rates throughout the paddock. The more variation in emitter flow rates the lower the uniformity. Differences in emitter flow rates are caused by:

- Physical variations in each emitter from the manufacturing process; the degree that one emitter varies from another is called the coefficient of manufacturing variation which is abbreviated to CV;
- Pressure variation within the system, this is caused by friction in the pipes and fittings and differences in elevation; the degree of variation depends upon the initial design and then how well the system is operated and maintained;
- Sensitivity of emitter to flow rate. For most drip emitters as the water pressure increases so does the flow rate, the relative sensitivity of the emitter flow rate to pressure differences is called the emitter exponent; different emitter types and manufacturers have different exponents; and
- Emitter clogging, the main cause of variation in drip systems, can quickly reduce a system designed with a high uniformity to one with a very poor uniformity

The importance of uniform water application cannot be overstated. With a drip system it is physically not possible to apply large amounts of water across a paddock as occurs with furrow irrigation, thus if some plants are not receiving adequate water there is no way of rectifying the problem with a large irrigation to rewet the entire soil profile. The benefits of drip irrigation are largely lost if the system has poor uniformity since optimal water management over the whole paddock will be unachievable, some areas will be too dry, some too wet. If this is the case, then the economic benefits of yield and quality will also be lost and the whole enterprise may be uneconomic.

The uniformity of a drip system is characterised by its distribution uniformity - also known as emission uniformity. The distribution uniformity is calculated by dividing the minimum emitter flow rate or average of the lowest 25% of emitters by the average flow rate of all the emitters (Burt and Styles, 1994). The total distribution uniformity is a combination of the emission variation due to uneven pressure distribution throughout the paddock and the variation due to the manufacturing variation. Practically, paddock design distribution uniformities should be >90%.

Appendix 3: Drainage needs and infrastructure in the major irrigated regions

Provided by E.W. Christen and J.W. Hornbuckle

Murrumbidgee and Coleambally Irrigation Areas in New South Wales

Both the Murrumbidgee (MIA) and Coleambally (CIA) Irrigation Areas have extensive areas with water tables less than 2 m from the ground surface. Shallow water tables have little detrimental effect on the (predominant) rice crops but significant areas of remnant and roadside vegetation have been affected as were perennial horticulture areas prior to sub surface drainage installation.

Drainage in the rice growing areas:

In some MIA areas where rice is the main crop, experimental subsurface drainage was trialled using shallow groundwater pumping to decrease the risk of water-logged and saline conditions affecting farming operations and crops other than rice. Shallow spearpoints were installed but extraction was discontinued due to the high salinity of the discharge water and uncertain benefits in a rice-based farming system. Shallow vertical pumping and horizontal drainage have also been tried with extracted water discharged to evaporation basins and some reuse. More extensive drainage has not proceeded due to the high costs compared with relatively low benefits in a rice-based farming system. Assessment of very low drainage rates for this type of cropping system is an area for future research.

In the Coleambally area experimental deep groundwater pumping (>120 m) has been undertaken to assess the benefits for salinity control. There appeared to be a drawdown of 0.1 – 0.3 m over several years, within 2 km of the experimental bore. The effect of such small draw down on salinity control is uncertain. It is clear that the linkage between deep and surface aquifers is poor at the experimental bore location and, thus, there is relatively limited potential for deep pumping to assist in salinity control in that area.

Drainage in the horticultural areas:

The MIA has approximately 10,000 ha of horticultural plantings with horizontal subsurface drainage. The impetus to install drainage came in the mid 1950s when 50% of the tree crops were killed by waterlogging after two successive years of above average rainfall. This led to a concerted research effort into horizontal 'tile' drainage and a system of Government loans for implementation. The research developed drainage criteria, methods for site investigation (hydraulic conductivity) and nomographs for design.

Until recently, it has been standard practice to install subsurface drainage in all perennial horticulture, almost all of which was irrigated with surface furrow systems. Some newly established vineyards using drip irrigation have not installed subsurface drainage although the sense of this has not been tested in the long term. Water from perennial horticulture (~ 2 – 12 dS/m) tile drains is pumped from a central collection well via electric pumps on each farm and discharges into the surface drainage open channel system. This drainage water mixes with all other drainage (both surface and subsurface) from the region and flows via Mirrool Creek to Barren Box Swamp. This extensive holding basin is used as a supply source for the Irrigation Districts to the west of the MIA.

Excessive drainage during the early 1980s led to a moratorium on additional drainage so that new horticultural developments have had to manage their discharge on farm using evaporation basins. This has led to the development of 15 on farm evaporation basins in the area.

The major issue facing the area is subsurface drainage effluent treatment and storage. Volumes from existing systems need to be reduced and future systems will have to use evaporation basins. An overall drainage management plan is required for the area.

New South Wales Murray region

Irrigation recharge has occurred over extensive areas so that many now have shallow water tables <2 m from the ground surface. Subsurface drainage to address this problem has been in the form of shallow groundwater pumping. The pumping strategy has been to maintain water tables at about 2 m under rice and pasture (perennial/annual) dominated cropping. Groundwater pumping has been dominated by the Wakool-Tullakool scheme providing protection to about 30,000 ha which drains to a 2,100 ha evaporation basin. This scheme was developed in the 1980s and has been successful in reducing the area of high water tables (<2 m). This major development was funded by State government.

Since that period there have been numerous private groundwater pumps installed. These are for conjunctive reuse directly or by discharge into surface drains and irrigation channels. Much of this water is quite saline and has high sodicity levels. In recent times, with restricted surface water supplies because of the drought, there has been an increase in groundwater pumping for direct irrigation use.

Future issues are associated with the high levels of reuse of poor quality groundwater, which may be unsustainable in terms of soil salinisation/sodification and maintaining aquifer quality. Research into conjunctive reuse is required to clarify these issues. Further construction of evaporation basins to receive groundwater is being planned as increased groundwater extraction is seen as essential for future irrigation sustainability.

Shepparton Irrigation Area in the Goulburn Broken Region

Subsurface drainage in the Shepparton region is highly planned and coordinated under the Land and Water Salinity Management Plan.

Due to irrigation, shallow water tables are present under most of the area. This has led to waterlogging problems for perennial horticulture and salinity problems for perennial pasture. Drainage in the horticultural areas was rapidly implemented after serious waterlogging in the mid 1970s. Spear point systems were adopted where there were shallow pumpable aquifers, with horizontal drainage for other areas.

Pasture areas are protected by a much larger drainage strategy of public groundwater pumps for salinity control and promotion of private groundwater pumps for conjunctive reuse. This groundwater pumping was from shallow aquifers (< 20 m) with relatively good water quality, < 3.6 dS/m for private reuse. Water from public pumps is directed into the surface drainage network and the irrigation supply system. A 30 ha experimental evaporation basin has been in operation since 1982 for very saline water.

Overall, there is a detailed plan which has divided the area into four drainage classes each with appropriate drainage systems . Appropriate salinity levels have been determined for on farm reuse, regional reuse (via drains and irrigation channels) and river discharge. Drainage to the river is limited by the number of EC credits available to the area. This is an issue for future concern as the available credits may be inadequate.

Mechanisms have been developed for distribution of costs between direct beneficiaries, all landholders, local government and State government.

Future issues include available EC credits, discharge and storage options, better estimates of safe salinity reuse levels and better information on the long term impacts of groundwater pumping on aquifer water quality.

Kerang area (Loddon Campaspe region)

This area has suffered extensively from salinity problems partly because of regional groundwater discharge. With the development of a local groundwater mound from irrigation activity combined with the upward pressures of the regional groundwater, there is little wonder that soil salinisation would result. Extensive investigation has been conducted in the region into subsurface drainage methods. Both vertical and horizontal drainage has proved to be effective. Groundwater salinity is very high (~20-50 dS/m) so that in most cases salt in the drainage water needs to be stored in evaporation basins. Subsurface drainage discharging to evaporation basins is a high cost solution so there are relatively few operating systems. Where the groundwater quality is good (<5 dS/m) then conjunctive reuse on perennial pasture is successfully undertaken.

Research into design criteria for the area suggests that the water table needs to be controlled to avoid having saturated conditions less than 1 m from the ground surface to control the rate of capillary rise to less than 0.1 mm/d. Experience has shown that very low drainage rates can be effective in pasture production situations. Leaching fractions of only 2-5% may be necessary together with control of the upward (artesian) pressures. This may equate to an overall drainage rate of 0.8 mm/d (~ 3ML/ha/yr).

Research into vertical drainage with extended well points and evaporation basin storage suggests costs of $1,380/ha, whilst horizontal drains with evaporation basin cost about $2,280/ha.

Future issues relate to reducing the cost of drainage by investigating the effectiveness of very low drainage rates.

Sunraysia Region

This region is similar to the Riverland in drainage problems and solutions. Predominantly perennial horticulture, horizontal drainage was installed as protection from waterlogging, from the 1920s. Experiments were conducted to determine appropriate drain spacings according to soil type. Drainage water from these systems is directed to the Murray River and evaporation basins.

Future issues are associated with continued drainage flows into the river and the development of new irrigation areas. New areas are required to set aside land for evaporation basins. However, many developments are using controlled irrigation and are suggesting that subsurface drainage will not be required. Long term requirements for perennial horticulture using controlled irrigation (drip/sprinkler) are as yet unclear.

Riverland in South Australia

This area is dominated by perennial horticulture. From the 1920s, horizontal drainage was installed as protection from waterlogging following experiments to determine appropriate drain spacings according to soil type. The drainage water from these systems was initially injected into deeper, more permeable aquifers or to the Murray River. Discharge to the deeper aquifers exacerbated the build up of the groundwater mound under the irrigation area and increased discharge of saline groundwater to the river. Now discharge is to evaporation basins located on the Murray River floodplain or in highland areas away from, the river.

Future issues will be associated with moving evaporation basins away from the river floodplain and reducing drainage flows.

Appendix 4: Measuring water use efficiency and water use productivity

Provided by E. W. Christen and N. Jayawardane

With increased pressure on using resources more effectively, water use efficiency and water productivity (WUEP) must be increased to maintain irrigated crop production with reduced water supplies and to minimise the effects of poor irrigation practice on soil, land and water resources. Assessment of current water use in irrigation schemes is required so that we can identify the potential for future improvements in WUEP. This should be carried out within a rigorous WUEP framework that defines the measures that need to be made and how they relate to one another.

The terms 'water use efficiency' and 'water use productivity' have been used with various engineering and agronomic connotations in many studies. The lack of consistency in both definition and subsequent use has caused considerable confusion. Several studies (Howell 1997, Barrett Purcell and Associates 1999, Smith 2000, Schmidt 2001, Molden et al. 2003, Purcell and Currey 2003, Fairweather, Austin and Hope 2004) have attempted to provide a comprehensive framework for defining water use efficiency and water use productivity at different scales.

We have adopted a framework based on Smith (2000) and Schmidt (2001) for evaluating WUEP at field, farm and irrigation area scales. Smith (2000) described and defined the relationships of WUEP parameter measurements at each step in the water conveyance and irrigation process. The connections between parts of the processes are illustrated in Figure 44, which was primarily derived from Schmidt (2001). It has been modified to add in the water accounting approach proposed by Molden (1997) and Molden et al. (2003). Molden's approach is especially useful in capturing the effects of other water issues at larger catchment scales, such as water reuse and water quality changes. It also distinguishes tangible and realisable water savings from those ideal water savings that cannot be captured.

From the engineering perspective, irrigation efficiencies are affected by water losses in the successive steps from the main supply to the farm boundary (**Conveyance Efficiency** – Cell 1 in Figure 44 below), from the farm boundary to the field or paddock boundary (**Farm Efficiency** – Cell 2 in Figure 44), and from the field boundary to the root zone in the paddock (**Field Efficiency** – Cell 3 in Figure 44). Field efficiency is the fraction of the water applied to the field that is effectively stored in the root zone for subsequent uptake by crops.

The total water loss in the entire hydraulic flow system can be calculated by combining the conveyance, farm and field efficiencies, and is referred to as the **Irrigation Efficiency** (Cell 5 in Figure 44). Rainfall supplements the irrigation water supply to the farmer's paddocks, and **Rainfall Efficiency** (Cell 4 in Figure 44) is the fraction of rain that infiltrates into the soil and is stored in the root zone for subsequent uptake by crops.

The agronomic perspective focuses mainly on the efficiencies associated with the crop uptake of water stored in the root zone and its conversion into saleable plant products, which are identified in Cells 6, 7, 8 and 9 of Figure 44.

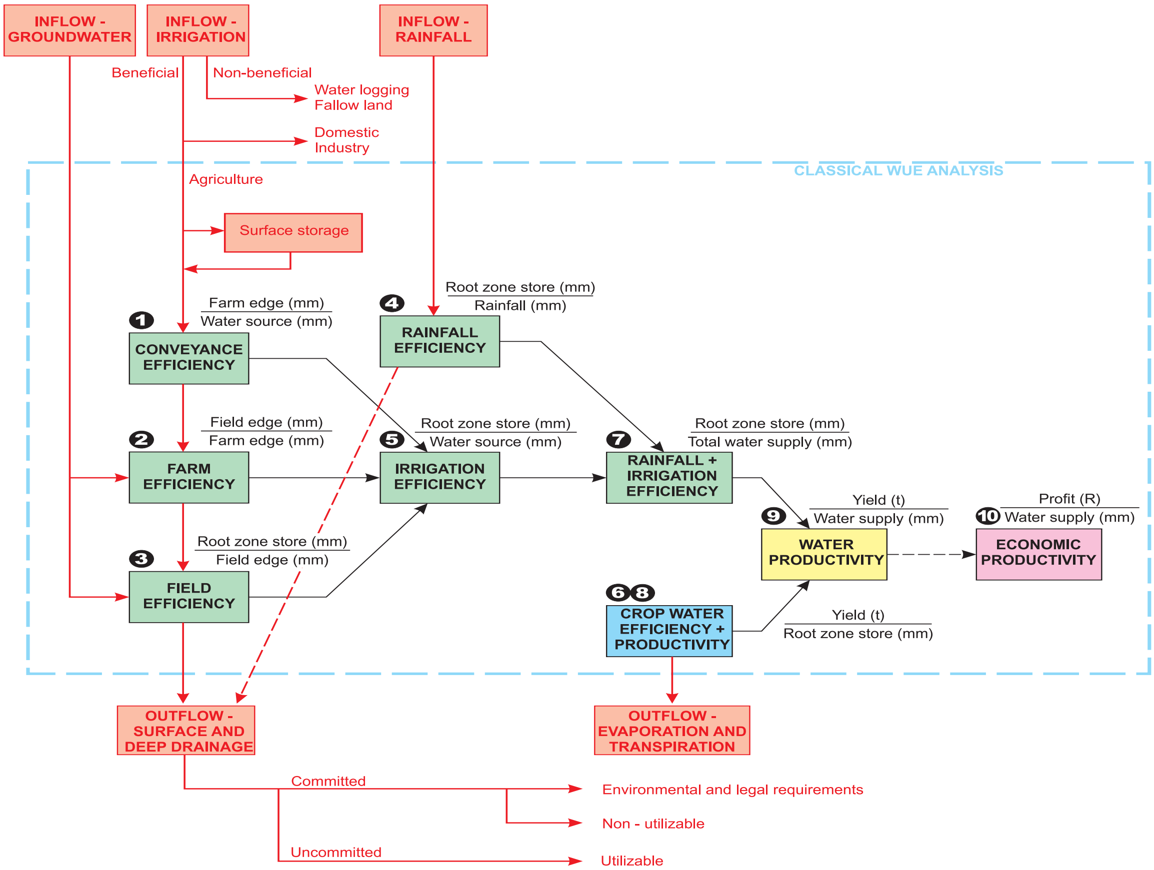


Figure 44 – An assessment framework for describing the water use efficiency and water use productivity of an irrigated system.

Crop Water Efficiency (Cell 6 in Figure 44) is defined as the fraction of water stored in the root zone that is used for crop transpiration and is described by Smith (2000), as follows: Water stored in the soil is taken up by crops for transpiration, while a portion is lost through evaporation at the soil surface. In addition, any stored soil water that is not used results in a net increase in soil water available for use by the next crop.

The amount of evaporation from the soil surface depends on the wetness of the soil surface, humidity, temperature, wind speed and solar irradiance at the soil surface, which are influenced by the degree of crop growth and shading. This in turn is linked to the crop growth characteristics. When the crop is small, soil evaporation predominates after rainfall or irrigation wets the soil surface. The evaporation rate decreases rapidly as the soil surface dries. As soil evaporation is difficult to separate from the water requirements for crop transpiration, the crop water requirements estimates traditionally incorporates both crop transpiration and soil evaporation and are termed crop evapotranspiration.

The procedures described in the FAO Irrigation and Drainage paper No. 56 (Allen et al. 1998) allow estimation of crop evapotranspiration (ETcrop) according to

$$ETcrop = Kc\ ET0 = (Kcb * ET0) + (Ke * ET0)$$

Where Kcb* ET0 represents crop transpiration and Ke* ET0 represents soil evaporation, and where Kc, Kcb and Ke are coefficients. The crop water efficiency can be simplified as

Crop water efficiency = Kcb / Kc

Allen et al. (1998) provide values of crop water efficiency for different crops at different growth stages. He also proposed a methodology to make adjustments for climatic conditions and different irrigation systems.

The overall **Water Use Efficiency** (Cell 7 in Figure 44) is obtained by combining the rainfall, irrigation and crop water efficiencies.

The **Crop Water Productivity** (Cell 8 in Figure 44) is the ratio of yield to transpiration and can be expressed in units such as kg m-3. It involves factors influencing the conversion of water into carbohydrates and, ultimately, crop biomass and yield and is described by Smith (2000) as follows. Crop growth is governed by photosynthesis where carbon dioxide and water are converted into carbohydrates fuelled by solar irradiance. Transpiration of water is also directly linked to photosynthesis, as the transport of carbon dioxide and water share a common pathway through the stomata.

Hence, there is a direct relationship between the amount of carbon assimilated and amount of water vapour transpired (Steduto 1996). This relationship is determined by the crop-specific photosynthetic productivity (PSP), which is more or less constant over different growth stages in a given crop. The assimilated carbon dioxide is converted into biomass which requires temperature dependent expenditure of energy. Indicative figures for respiration efficiency (RE) expressed as the ratio of biomass/assimilates, ranges from 0.5 to 0.65. Only a part of the biomass produced is converted into the final harvested yield, and the ratio of yield to total above ground biomass is referred to as the harvest index (HI). The harvest index normally varies from about 0.3 to 0.5. Plant breeding has produced marked increases in harvest index, but has had only a small influence on biomass water productivity. Crop water productivity can hence be given by the following equation.

*Crop water productivity = PSP * RE * HI*

The genetic characteristics of the crop are the primary factors governing crop water productivity. They determine the assimilation characteristics, the respiration and physiological processes that convert assimilates into biomass and the harvest index that partitions biomass into harvestable product.

The other factor that affects crop water productivity is the reaction to water deficit stress, which, in certain critical growth periods, may affect the vital growth processes and strongly reduce the harvest index or induce compensatory processes that off-set the negative effects of interruptions to photosynthesis.

Two distinct crop types are recognized according to their reaction to water stress, ie crops which are sensitive to water stress and require reliable high water supply and crops that are tolerant to drought and can be grown as low-irrigation or rainfed crops.

The Water Productivity (Cell 9 in Figure 44) is obtained by combining water use efficiency with crop water productivity.

In calculating the parameters in Cell 6, 7 and 9 in Figure 44 for a particular cropping season, the carry over of stored soil water from the previous season and into the next season needs to be accounted for.

The Economic Productivity (Cell 10 in Figure 44) can be calculated by allocating a price to the yield term in the water productivity analysis, as determined by the market value of the harvestable product. Many different economic parameters could be introduced into the yield and water supply factors used in this analysis, to provide specific insights on the value of water that apply to specific irrigation locations.

Other water utilization efficiency parameters outside the integrated framework proposed by Smith (2000) have been suggested by some field researchers (Barrett Purcell and Associates, 1999; Cox et al., 2002).

It is often not possible to separately analyse Irrigation Efficiency and Rainfall Efficiency due to limited field data. Therefore, these two terms were combined into **Irrigation+Rainfall Efficiency**. This is not a disadvantage, as making better use of rainfall is important for irrigation. In the modified framework we also combine soil evaporation and crop transpiration, which is much easier to measure or estimate as total crop evapotranspiration in the field, and use this combined value in estimating the modified WUEP parameter **Crop Water Efficiency+Productivity**.

Appendix 5: What research activities are needed by irrigation communities and irrigation industries?

- This study clearly indicates that there has been considerable improvement in the management of water both in delivery and on farm application. However there is also clear evidence that there are still considerable gains to be made from improving irrigation delivery and application. As a greater proportion of the irrigated production moves to more controlled systems so the demand for delivery to be provided on a demand basis will increase. In those regions where there is long delivery time from storage to application the only way forward will be to use the delivery system capacitance to greater advantage (use channels for storage as well as supply), to increase on route and on farm storage, and to use groundwater storage and recovery to greater advantage. Research is needed to develop the extent of these options and to identify those areas where different options could be applied.
- The evidence from this study shows that the most progress in updating and upgrading irrigation practice occurs on a region by region basis. (Regions are those in which there is a shared sense of community through a common sense of threat or opportunity). There is little evidence that focusing on a particular industry is highly successful. The major exception to this is the rice industry which has a long history of coherence (mostly the result of a cooperative monopoly). At the other end of the spectrum the major and impactful dairy industry has shown little inclination to pursue an aggressive research and farm practice reform agenda. Where improvement in water use productivity has occurred in the dairy industry it has been strongly related to highly supportive extension efforts mostly emanating from the local region.
- For regions to be successful in changing to improved practice there needs to be the alignment of many factors. The first is an apparent and imminent imperative to act, (more usually from a threat rather than an opportunity) that comes from the fear of limiting access to resources, greater regulatory control or an impending catastrophic impediment to current practice e.g. salinity or waterlogging. The call to action is usually only highly successful if there is then a coincidence of institutional change and individual commitment. Where these actions have coincided such as in the Riverland, Sunraysia, Coleambally and some districts in NSW Murray and the Goulburn regions there is demonstrable and rapid investment with good returns. Research, extension, education, learning and service provision must all play a part in supporting change. The availability and continued commitment of regional leadership is a critical factor as is an institutional culture that values innovation and a diversity of views.
- Sharing the irrigated landscape will become more critical as the interplay between agricultural production, urban and industrial development and rural residential developments occur. The heightened awareness of real and potential impacts from effects such as chemical use, nutrient flows into surface and groundwater and simple access to water and land resources means that irrigators cannot remain in blissful ignorance of their effect on the surrounds. Processes which generate a sense of fairness and equity in the use of and sharing of resources are part of the social process that needs to develop for successful co-existence. Studying and testing the possible combinations of intensive production systems and environmental service provision and even bio-diverse conservation areas mixed with irrigation needs to be explored – along the lines of mosaic systems.
- The interdependency and connectedness of water (water supply, extraction, surface water delivery, rainfall and above all, groundwater connections) needs to be better understood. Associated with this is the need in all irrigated regions for water and salt balance studies of the kind demonstrated in the Murrumbidgee. The lack of accurate

measures must be remedied. One way to bring focus to these processes is through a renewed commitment to drainage research. The criteria for drainage are in urgent need of updating and making relevant to Australian regional conditions. This is becoming more important as we move to more controlled forms of irrigation and the very generous leaching that has been characteristic of our irrigation practice to this time means we need to improve our understanding and management if we are to avoid salting out the soil right next to our confined root systems. Thus the need for salinity management will be on-going – especially the interaction with groundwater and the longevity of controlled irrigation on soils of various types.

- More controlled forms of irrigation need to be assessed in all areas – it is encouraging that the possible application of sub-surface irrigation for pasture production is being contemplated – even if this does not prove to be economic currently, the fact that there is a modicum of different thinking and experimenting in this area should be encouraged.
- The variability of water supplies through climatic conditions will continue and on current indications this variability may increase. Combined with the greater demand and value of water this means that there will be decreased “slop” in water availability and increased management demand for timely forecast and intervention. Anecdotally, temporary water trading has probably lessened the impact of the unprecedented drought conditions in the last 3 years relative to what it may have been. However with variability likely to increase, less opportunity for short term flexibility and greater demands on multiple use of water it means forecasting of supply and demand will become more critical, trading flexibility will need to increase and storage, supply and distribution systems will need to be more effectively run. System research that brings this together (forecasting, risk assessment, operational efficiency and production sensitivity) to synchronise supply and multiple demand will be needed. As part of this systems approach, more explicit and regionally managed connections between irrigators and river managers are needed. There are opportunities for synergistic trade between water requirements for environmental flow purposes and irrigation requirements – we need more work on identifying the policy and operating guidelines that will be needed to bring effect to this connection.
- In all irrigation practice the major driver is the need to replace water that is evaporated from the crop and the ground surface. Yet our measurement of this amount on a daily or shorter term basis is still quite approximate. Exploring new methods of direct measurement of evapotranspiration at paddock and farm scale is a priority if we are to increase the accuracy of irrigation applications. As part of the need to more accurately estimate water use by crops there is need to find cost effective ways of bringing remote and in field data sources together. This may enable the variable water use by the same crop throughout the year to be quantified, and if possible a simple descriptive parameter developed that improves on crop coefficients.
- Connected with the need for on going work on controlled forms of irrigation is a broader and over arching issue of the energy balance of irrigated practice. We are just beginning to see the signs of a very different energy future where current energy sources will be much more expensive in real terms. Understanding the immediate and embedded energy requirements in every irrigation system and its potential return (energy and $’s) will be an important part of preparing the irrigation industry for the future.
- Closer links and more concerted work are needed between water and nutrient application and plant physiology to regulate the saleable product.
- In compiling this study, the usual and much written about lack of consistent data collection was very evident. However the recent efforts through the MDBC are improving this situation with respect to water recording. Regional activities such as

the Sunrise 21 effort in the Sunraysia set a standard that needs to be replicated in all the other regions. An unexpected and frustrating aspect of this current study compilation was the fragmented and poorly documented activities associated with environmental works. There is some documentation and data that connects irrigation activities with environmental goals and targets contained in the Land and Water Management Plans. Reporting against these Plans is variable in quantity and quality. It should also be borne in mind that there are still many irrigators, especially direct river pumpers who are not part of regional Land and Water Management Plans and do not have to comply with regional guidelines. It is also evident that there are a number of other activities such as wetlands working groups whose activities are affecting the water regime but whose connection to local irrigation practice is cursory. A "birds eye" review of all of the current activity, its connection to irrigation practice and its likely effect on water is needed. The fragmented and rapidly changing nature of the current activity in this area has made it difficult for this study to collate, analyse and synthesis this at a level that it needs.

Abbreviations used

ABS	Australian Bureau of Statistics
ANCID	Australian National Committee on Irrigation and Drainage
ANN	Artificial Neural Network
BRS	Bureau of Resources
BTRE	Bureau of Transport and Regional Economics
CIA	Coleambally Irrigation Area
CICL	Coleambally Irrigation Cooperative limited
CIT	Central Irrigation Trust
COAG	Council of Australian Governments
DIPNR	Department of Infrastructure, Planning and Natural Resources (NSW)
DWLBC	Department of Water, Land and Biodiversity Conservation
DWR	Department of Water Resources
FMIT	First Mildura Irrigation Trust
GHID	Government Highland Irrigation Districts
G-MW	Goulburn-Murray Water
MDB	Murray-Darling Basin
MDBC	Murray-Darling Basin Commission
MDBMC	Murray-Darling Basin Ministerial Committee
MIA	Murrumbidgee Irrigation Area
MIL	Murray Irrigation Limited
NLWRA	National Land and Water Resources Audit
PIRSA	Primary Industries and Resources, South Australia
SARDI	South Australian Research and Development Institute
SKM	Sinclair Knight Merz
SMEC	Snowy Mountains Engineering Corporation
SRWSC	State Rivers and Water Supply Commissioin
WUEP	Water Use Efficiency and Productivity

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