# Environmental economics and the Murray–Darling river system

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**Abstract**

Much concern about the negative environmental consequences of agricultural development in Australia, including salinisation, waterlogging and algal blooms, has focused on the problems of the Murray–Darling Basin. The aim of this paper is to provide an overview of the environmental problems of the Murray–Darling Basin from an economic perspective, and a selective survey of the relevant economic literature, including theoretical analysis, modelling and contributions to the development of water policy. In attempting to understand the complex problems of the Murray–Darling Basin, an eclectic approach drawing on externality, sustainability and property rights perspectives seems most appropriate.

**Keywords**

salinity, irrigation, externality, sustainability, property rights, Murray–Darling Basin

**JEL code**

## Environmental economics and the Murray–Darling river system

The Murray–Darling river system has long played an important role in the Australian agricultural sector, and an equally important role in Australian thinking about the agricultural sector. The development of irrigated agriculture was a central component of the policies of closer settlement and national development that were adopted from the 19th century to the late 20th century. More recently, much of the concern about the negative environmental consequences of agricultural development has focused on the problems of the Murray–Darling Basin including salinisation, waterlogging and algal blooms. The aim of this paper is to provide an overview of the environmental problems of the Murray–Darling Basin from an economic perspective, and a selective survey of the relevant economic literature.

The paper is organised as follows. The first section provides background information on the Murray–Darling river system, the history of irrigated agriculture and the main environmental problems of the Murray–Darling Basin. Next the evolution of policy is discussed, with particular emphasis on the replacement of the River Murray Waters Agreement by the Murray–Darling Basin Agreement and the imposition of a Cap on diversions of water from the river system for irrigation. The major environmental problems associated with irrigated agriculture and land clearance are outlined. The next section of the paper deals with frameworks for the economic analysis of environmental problems based on the concepts of externality, private and common property rights, and sustainability. These concepts are applied to the analysis of the Cap on irrigation diversions and to the design of policy responses to dryland salinity.

# 1. Background

## *1.1 The river system*

The Murray–Darling Basin covers just over one million square kilometres, or around 14 per cent of the area of Australia, and spans four states (New South Wales, Queensland, Victoria and South Australia) as well as the Australian Capital Territory.

**Figure 1 near here**

A detailed description of the system and its resources is given by Murray–Darling Basin Commission (2000a).

Compared to other river systems of similar size, the Murray–Darling Basin is characterised by low average rainfall and very high variability in rainfall. Because of these characteristics, irrigation can greatly enhance the value of agricultural output. Although there are no reliable measures of the aggregate value added for irrigated agriculture in the Murray-Darling Basin, the Basin accounts for about 70 per cent of the total area of irrigated land in Australia. Cape (1997) suggests that irrigation accounts for around 25 per cent of the total gross value of agricultural output in Australia, or around $7 billion per year, implying that the share of gross output associated with the Murray-Darling Basin would be around $5 billion per year. This is broadly consistent with the baseline estimate of Hall, Poulter and Curtotti (1993) that aggregate gross margins for the southern Murray-Darling Basin total about $1 billion per year.

The same characteristics, in combination with the working of the policy process, have contributed to many of the difficulties that have arisen in resource management in the Basin. In particular, the variability of flows has encouraged over-allocation of irrigation water leading to problems of unreliable supplies, low residual flows and conflict between upstream and downstream water users.

## 1.2 History of irrigated agriculture

Although individual farmers have undertaken small-scale irrigation from the early days of European settlement, the history of irrigated agriculture in the Murray–Darling Basin has been dominated by government or government-sponsored initiatives. The ideas of ‘closer settlement’ and of ‘development’, which played such an important role in the Australian policy debate in the late 19th and early 20th century, found a natural expression in government support for irrigated agriculture.

Irrigated agriculture was suited to operation on the small scale associated with schemes for closer settlement. Moreover, irrigation offered the potential for replacing low-intensity pastoral activity with high-intensity horticultural and grain cropping, thereby assisting the policy objective of developing Australia’s natural resources. Economic considerations were, initially at least, subordinated to the objectives of development and closer settlement.An important example of government involvement in the early development of irrigated agriculture was the support provided by the South Australian and Victorian governments to the Canadian Chaffey brothers in their development of the Renmark and Mildura irrigation settlements in 1887.

The Snowy Mountains Hydro-Electric Scheme was the most important single national development project undertaken after World War II. Although its primary purpose was power generation, the Scheme's contribution to further development of irrigation in the Murray–Darling Basin was an important part of its political appeal.

The combination of large-scale, predominantly public, irrigation projects and direct diversions by individual farmers led to steady increases in diversions of water for irrigation from the Murray–Darling Basin.

The intensity with which water is used in agricultural production varies greatly depending on the commodity being produced and the irrigation techniques employed.

Micro-irrigation techniques applied to high-value crops yield a very high return per unit of water applied, while flood irrigation applied to pastures yields very low returns. The water requirements for selected commodities, using the most common irrigation techniques for the commodity in question, are shown in Table 1.

**Table 1: Water required for $1 000 gross profit**

| Commodity | Water use (Ml) |
|---|---|
| Fruit | 2.0 |
| Vegetables | 4.6 |
| Dairy products | 5.0 |
| Cotton | 7.6 |
| Rice | 18.5 |
| Pasture | 27.8 |

Source: Hall, Poulter and Curtotti (1993)

One way of interpreting Table 1 is to consider the implications of changes in water prices for profitability. For example, if the price of water increased by $40 per Ml, the use of irrigation for pasture would become unprofitable, and the gross margin from irrigated rice production would fall by nearly 75 per cent. By contrast, the profitability of fruit and vegetable production would barely be affected.

## *1.3 Environmental problems*

The development of agriculture in the Murray–Darling Basin has been associated with a range of environmental problems, some of which are specifically linked to irrigation while others reflect more general impacts of agriculture. The problems affecting the Basin as a whole may be divided into five main categories: land degradation; river water salinity; land salinity; water quality problems; and loss of biodiversity. However, it must be noted that all of these problems are inter-related.

First, there are general land degradation problems such as soil erosion, acid soils, native vegetation decline, and the impact of weeds and noxious plants. Because these problems are not specific to irrigated agriculture, or to the Murray–Darling Basin, they will not be discussed in detail here. However, these problems must be taken into account in formulating a response to environmental problems more directly related to irrigation.

Second, there are problems associated with salinity of river water. Irrigation tends to increase salinity because runoff increases salt loads and because the use of water for irrigation reduces total flows. Saline water can reduce the yield of irrigated crops and damage water pipes and domestic appliances. Reductions in yields of sensitive crops, such as stonefruits, are observed at salinity levels in excess of 200 EC and for citrus fruits at 300 EC. [1] The quality of water for human consumption deteriorates perceptibly when salinity exceeds 300 EC, and water with salinity greater than 800 EC is considered unacceptable for human consumption. The Salinity Audit undertaken by the Murray-Darling Basin Ministerial Council (2000, p. vi) concluded that, under current policies

> The average salinity of the lower River Murray (monitored at Morgan) will exceed the 800 EC threshold for desirable drinking water quality in the next 50–100 years. By 2020 the probability of exceeding 800 EC will be about 50 per cent.

Third, there are problems of land salinity, arising primarily from rising water tables. Dryland salinisation is primarily associated with the clearance of deep-rooted native trees and their replacement with shallow-rooted crops and pasture. In addition weir pools may create a freshwater 'dam' that precludes the drainage of salty water into the river system.

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1 The EC unit is a measure of electrical conductivity, commonly used to indicate the salinity of water. 1 EC = 1 micro-Siemen per centimetre, measured at 25° C.

The effect is to raise the water table in the catchment in which clearance takes place, and therefore to bring saline water closer to the surface. As the groundwaters rise, naturally-occurring salts (principally sodium chloride) are dissolved and brought towards the surface, where the water evaporates leaving high concentrations of salt. In addition to the effects of salinity on crops, vegetation and wetlands, rising water tables cause waterlogging of land and damage to roads and buildings. However, this process is not uniform. The effect of tree clearance on water tables is greatest when trees are cleared on recharge areas, but the resulting salinisation takes place primarily in discharge areas. The issue is complicated by more general concerns relating tree clearance to loss of biodiversity and to an increase in net emissions of greenhouse gases.

Fourth, there are water quality problems other than salinity, including turbidity, and eutrophication resulting from excess nutrients such as fertiliser runoff. Eutrophication is associated with algal blooms such the blue-green algae bloom which occurred in the Darling River in 1991-92, and which was described as ‘the largest river bloom of blue-green algae recorded anywhere in the world’ (Murray–Darling Basin Ministerial Council 1994, p. 3). These problems have been exacerbated by the effects of introduced species such as European carp.

Finally, there are problems of biodiversity and loss of habitat, particularly those arising from changes in the patterns of river flows, and the reduction in the volume of water flowing into wetlands such as the Macquarie Marshes. In the last few years, there have also been proposals to restore flows to the Snowy River, 99 per cent of which is currently diverted to the Murray–Darling Basin through the Snowy Mountains Hydro-Electric Scheme.

## 2. Policy

Following the terminology of Randall (1981), the evolution of policy regarding the Murray–Darling Basin may be divided into two phases: an expansionary phase, which coincided with the operation of the River Murray Waters Agreement; and a mature phase, reflected in the adoption of the Murray–Darling Basin Agreement. The crucial event thus far in the mature phase has been the imposition of ‘the Cap’, a limit on aggregate diversions of water from the Murray–Darling Basin.

*2.1 The River Murray Waters Agreement*

Regulation of the Murray River system was one of the first issues addressed after Federation. A period of drought beginning in 1895 culminated in the ‘Federation drought’ of 1901–2. One result was a non-government conference held in Corowa in 1902, which called for government action to manage the waters of the Murray River. (Murray–Darling Basin Commission 2000b).

A prolonged period of negotiation followed, during which the states claimed property rights over the waters of the Murray and its tributaries. South Australia relied on provisions of the newly-enacted Constitution under which the Commonwealth government had authority over navigation along the Murray River and an implied obligation to preserve flows in the South Australian section of the river. Although the navigation rationale soon lost its relevance, South Australia’s claim of rights to some minimum flow was consistent with doctrines of prior appropriation. The upstream states, Victoria and New South Wales, favoured the riparian doctrine, under which landowners are free to take water from streams flowing through their property. As the ‘Premier State’, New South Wales claimed riparian rights not only over its own rivers, but over the entire main stream of the Murray. Although the border between New South Wales and Victoria was determined to follow the southern bank of the river, Victoria successfully claimed equal rights over the river flow.

Negotiations were finally concluded in 1915. The River Murray Waters Agreement, to which the Commonwealth and the states of New South Wales, Victoria and South Australia were parties, set out the basic conditions which remain in force today:

- flow at Albury is shared equally between New South Wales and Victoria
- Victoria and New South Wales retain control of their tributaries below Albury
- Victoria and New South Wales supply South Australia with a guaranteed minimum quantity of water

The agreement also provided for construction of dams, weirs and locks on the main stream of the Murray to be managed by the River Murray Commission (predecessor of the current Murray–Darling Basin Commission) which was established in 1917 (Murray–Darling Basin Commission 2000b). The River Murray Commission owned and operated the structures, but this function has now been divested to a separate organisation, River Murray Water, in line with current thinking about the desirability of separating regulatory and operational functions.

Although it was an important example of cooperative federalism, the River Murray Waters Agreement was limited to the management of water for irrigation and navigation. As Clark (1982) notes most environmental issues were matters beyond the powers of the River Murray Commission and were left to individual states to resolve.

*2.2 The Murray–Darling Basin Agreement*

Recent developments in policy regarding the Murray–Darling Basin reflect the constraints associated with a maturing water economy (Watson and Rose 1980; Randall 1981). Randall argues that where the exploitation of irrigation opportunities is in its early stages, we observe an expansionary water economy, characterised by relatively low social cost of expanded water use, in total and at the margin. In such circumstances, the welfare cost of subsidies to water use is small. When the expansionary phase reaches its inevitable end, and a mature water economy emerges, the problem of managing the resource is complicated by the persistence of policies inherited from the expansionary phase. Randall's (1981) characterisation of the main features of expansionary and mature water economies is presented in Table 2.

**Table 2: Characteristics of expansionary and mature water economies**

| Item | Expansionary phase | Mature phase |
|---|---|---|
| Long-run supply of impounded water | Elastic | Inelastic |
| Demand for delivered water | Low, but growing: elastic at low prices, inelastic at high prices | High, and growing: elastic at low prices, inelastic at high prices |
| Physical condition of impoundment and delivery systems | Most is fairly new and in good condition | A substantial proportion is aging and in need of expensive repair and renovation |
| Competition for water among agricultural, industrial and urban uses and instream flow maintenance | Minimal | Intense |
| Externality etc. problems | Minimal | Pressing: Rising water tables, salinisation saline return flows, groundwater salinisation, water pollution etc |
| Social cost of subsidising increased water use | Fairly low | High and rising |

Source: Randall (1981, Table 1)

At least until the 1960s, the Murray–Darling Basin displayed all the characteristics of an expansionary water economy. As shown in Figure 2, the supply of irrigation water responded rapidly to growing demand. The physical infrastructure associated with the

Snowy Mountains Hydro-Electric scheme and the associated downstream irrigation systems was fairly new, and governments were willing to support these investments even when rates of return were low or negative. Environmental problems and competition for water use became evident during the 1970s. By the late 1980s, these problems were pressing and the transition to a mature water economy was largely complete. The aging of physical infrastructure coincided with an increase in real interest rates and increasing pressure to reduce public debt, making governments unwilling to finance new capital investments.

**Figure 2 near here**

As diversions for irrigation approached or exceeded the capacity of the Murray–Darling river system, and environmental problems became more serious, the need for a coordinated approach to management of the Basin as a whole became more evident. The Murray–Darling Basin Agreement was signed in 1987. In its initial form, it was as an amendment to the River Murray Waters Agreement. Five years later, in 1992, a totally new Murray–Darling Basin Agreement was signed, replacing the River Murray Waters Agreement. The Agreement was given full legal status by the *Murray–Darling Basin Act 1993* which was passed by all the contracting governments. Queensland also became a signatory, under terms set out in a Schedule to the Agreement. In 1998, the Australian Capital Territory formalised its participation in the Agreement through a Memorandum of Understanding.

The stated purpose of the Murray–Darling Basin Agreement is ‘to promote and coordinate effective planning and management for the equitable, efficient and sustainable use of the water, land and other environmental resources of the Murray–Darling Basin’ (*Murray–Darling Basin Agreement 1992,* Clause 1).

To achieve this, the Agreement established new institutions at the political, bureaucratic and community levels. These are:

- the Murray–Darling Basin Ministerial Council (MDBMC);
- the Murray–Darling Basin Commission (MDBC); and
- the Community Advisory Committee (CAC).

The principal business of the institutions established under the Agreement has been to formulate a response to the unsustainable growth in diversions of water from the Basin for irrigation and other purposes.

*The Cap*

Shortly after its formation, the Murray–Darling Basin Ministerial Council responded to the problem of excess demand for water. In 1995, the Council introduced a moratorium on the future growth in diversions of water from the Basin, which was replaced, from 1 July 1997 by a permanent upper limit to diversions, known as the Cap.

The Cap is defined as the volume of water that would have been diverted under 1993-94 levels of development. The Cap is not the *volume* of water that was used in 1993-94. Rather the Cap in any year is the volume of water that would have been used with the infrastructure (pumps, dams, channels, areas developed for irrigation, management rules and so on) that existed in 1993-94, assuming similar climatic and hydrologic conditions to those experienced in the year in question. Thus, the Cap provides scope for greater water use in certain years and lower use in other years (Independent Audit Group 1996). Under the agreement to implement the Cap, each state is required to implement a management plan for each of the catchments under its management.

*2.3 The Council of Australian Governments*

The development of policy with respect to the Murray–Darling Basin has been significantly affected by agreements reached by the Council of Australian Governments (COAG) including the National Competition Agreement. In February 1994, COAG endorsed an agreement for the sustainable reform of the water industry. COAG's Water Resource Policy called for clearer specification of users' rights and access to water, and the provision of water for the environment. The key objective was to encourage water use which will achieve its highest value among both consumptive and non-consumptive uses, while ensuring that the use is ecologically sustainable (COAG 1994). In April 1995, the Water Resource Policy became a component of the National Competition Agreement.

The general effect of the COAG agreements is to reinforce the policy preference for price-based and market-based solutions to environmental problems. However, the Competition Principles Agreement also requires that a number of matters shall, where relevant, be taken into account. The first of these is 'government legislation and policies relating to ecologically sustainable development'. The Australian Conservation Foundation has supported the application of National Competition Policy to water, stressing the requirement for sustainability. However, it is opposed to the creation of water rights with unlimited tenure (Australian Conservation Foundation 1994), which is arguably implicit in the program set out in the 1994 and 1995 COAG agreements. This conflict reflects the tension between private and common property rights.

## 3. Analytical frameworks

A wide range of analytical frameworks have been used by environmental economists to analyse environmental problems and propose policy responses. It is useful to distinguish three main frameworks, based on the concepts of externality, sustainability and property rights, respectively. The concept of externality is due to Pigou (1924). Coase (1960) challenged the Pigovian approach and argued instead for an analysis based on the concept of property rights. The origins of the concept of sustainability are less clear, and the range of approaches encompassed by the term 'sustainability' is much broader. The concept may be traced back to the idea of 'maximum sustainable yield' prominent in biological approaches to natural resource management, but uses of the term in economics have diverged considerably from this starting point.

Many debates between the advocates of these different approaches remain unresolved. An assessment of their strengths and weakness must therefore reflect personal judgements rather than professional consensus. In this paper, it will be argued that, for the analysis of complex problems such as those of irrigated agriculture, it is appropriate to take an eclectic approach, using different analytical frameworks in different contexts.

### *3.1 Externality*

Pigou (1924) sought, for the first time, to present a rigorous analysis of optimal government intervention based on neoclassical welfare economics. An action by a firm or individual is defined as having external effects if it directly affects either the productive capacity of other firms or the welfare of other individuals. The key idea is that the actions of one individual directly impinge on others, without any direct market interaction. Pigou proposed that taxes or subsidies could be used to internalise externalities, by equating the marginal private cost of externality-generating activities with the marginal social cost.

Many different concepts of externality have been analysed. A useful distinction is that between point-source externalities, diffuse or nonpoint externalities and congestion externalities. A point-source externality problem arises when a single firm generates externalities affecting one or more other firms or individuals. In the analysis of the problems of the Murray–Darling Basin, point source externalities are less important than diffuse or nonpoint externalities, which arise when many firms or individuals contribute to an external effect on one or more others.

A second crucial distinction is that between unilateral and reciprocal or congestion externalities. Unilateral externalities arise when the actions of one party generate externalities affecting another, but not *vice versa*. To the extent that the actions of upstream users degrade water quality for downstream users, the salinity problem may be viewed as a unilateral nonpoint externality.

Congestion externalities arise when members of a group generate negative externalities affecting each other. Congestion externalities frequently arise in irrigation areas. Application of irrigation water results in rising water tables, with consequent waterlogging and salinisation. However, because of the complex hydrology of water catchments, such problems rarely display the complete symmetry of textbook congestion problems. Activities such as tree clearance have most effect on water tables when they take place in recharge areas, but the consequences are most evident in discharge areas. Thus, to some extent, there is a unilateral externality that is generated by land users in recharge areas and affects land users in discharge areas (who may or may not be the same people).

The analysis of congestion externalities raises theoretical difficulties that are difficult to resolve within the externality framework. Imposition of a Pigovian tax in the presence of congestion may make all resource users worse off, unless the tax revenue is returned to users. This problem is likely to result in political resistance to congestion taxes, and may also distort incentives for locally-funded investments that enhance the value of the resource. But unless payments to users are made in a lump-sum fashion (which is difficult) the return of tax revenue may weaken or negate the incentive effects of the Pigovian tax.

The externality framework is most valuable in the consideration of unilateral externalities. Many policy problems involving unilateral externalities develop as variations on a common pattern. An activity is initially undertaken without recognition of any negative external effects. Over time, either because of an expansion in the scale of the activity, accumulation of stocks of polluting by-products, or because of improvements in scientific knowledge, negative external effects are recognised. The policy problem now generates a conflict between efficiency objectives, which can be achieved through taxation or regulation of the externality-generating activity, and equity concerns arising from the fact that investments in the activity have been made without any expectation of such taxation or regulation.

### *3.2 Property rights*

The property rights approach was advanced by Coase (1960) as part of a critique of Pigou’s externality approach, with its reliance on government intervention. Coase discussed unilateral externalities involving two parties, and propounded the famous ‘Coase theorem’ that, in the absence of transactions costs, assignment of property rights to either party would result in negotiations leading to a Pareto-optimal outcome.

In practice, however, unilateral externality problems are frequently characterised by significant transactions costs, such as those arising from strategic behavior. The property rights approach has proved more useful in dealing with complex interactions between multiple users of a resource.

Analysis of property rights in environmental problems initially focused on private property rights (Coase 1960; Scott 1955). Scott (1955) showed that private ownership of a fishery would yield a socially optimal outcome whereas open access (which Scott misleadingly referred to as common property) would not. These ideas were developed by the ‘property rights school’ including Demsetz (1967) and Furubotn and Pejovich (1974).

However, as Randall (1983) observed, the private property rights school found great difficulty in analysing changes in property rights. This is critical, since, within this framework, it is only through changes in property rights structures that environmental issues can be addressed. Randall (1983) distinguishes between two post-Coasian traditions; a Coase–Posner tradition, following Posner (1972), which advocates flexibility in property rights when this would promote efficiency, and a Coase–Buchanan tradition which emphasises security and stability of rights. Randall points out the weaknesses of the Coase–Posner tradition. In addition to the reduction in the value of rights, and the associated disincentives for investment, Randall points out that instability in property rights encourages 'rent-seeking' behaviour aimed at securing a reassignment of rights. The Coase–Buchanan tradition is based on a contractarian theory of rights, of the type specified by Buchanan (1977). Following a hypothetical initial assignment of rights, all subsequent changes would be through voluntary exchange or other consensual processes. This approach meets Randall's objections to the Coase–Posner tradition, but involves significant limitations of its own.

The private property rights framework provides some useful descriptive insights into environmental problems of this kind, but very little policy guidance. The Coase–Buchanan view, that property rights should be inviolate, is equitable only if the initial distribution of rights was equitable. Since the initial allocation of rights over the Murray–Darling Basin gave almost nothing to the environment, environmentalists have sought to change this allocation. The Coase–Posner view that property rights will evolve to take account of changing values is based on the assumption that there exists an activist judiciary, willing to make the necessary changes through its interpretation of common and statute law. In the Australian context, this is not a realistic assumption, and the Coase–Posner view gives little guidance to legislators or bureaucrats regarding the way in which property rights should be changed.

One response to the difficulties associated with the private property rights analysis has been an increasing interest in the concept of common property. Economists in the private property rights tradition had long used the term 'common property' as a synonym for 'no property'. As long as this terminology was confined to the study of open access resources, as in the work of Scott (1955), it was merely confusing. However when economists in this tradition, such as Demsetz (1967) were confronted with actual common property institutions, they readily assumed that their open access model was applicable.

The erroneous equation of common property with open access was popularised by Hardin's (1968) 'tragedy of the commons' description of the medieval open field system and the accompanying argument for private property rights solutions to modern environmental problems. The work of Ciriacy-Wantrup and Bishop (1975) and Dahlman (1980) refuted Hardin's description of the open field system. This was followed by work describing the actual operations of contemporary common property systems in less developed countries, such as that of Jodha (1986) and Wade (1987). The concept of common property has proved useful in the analysis of traditional irrigation systems (Mahendrarajah 1986). In the Sri Lankan system examined by Mahendrarajah, land is privately owned and operated, but irrigation works are common property, and access to water during periods of drought is collectively managed. Common property ideas have also been applied to more general environmental issues such as the management of airsheds and river systems.

A crucial observation about common property rights is that pure systems of common property are very rare. Systems of agricultural property rights typically involve a mixture of private and common property similar to that observed by Mahendrarajah (1986). In the medieval open field system, for example, privately-owned cattle were grazed on common pastures, which reverted to private ownership in the cropping phase of the rotation cycle.

The notion of common property has played an important role in modelling of the Murray–Darling system by Quiggin (1988a), Hall, Poulter and Curtotti (1993) and Sappideen, Kennedy and Dumsday (1998). These models share a common basic structure. The Murray river system is divided into a number of subregions, which are organised in a sequential fashion, from upstream to downstream. Hall et al. extend this idea by modelling the whole Murray–Darling system as a directed network, with the upstream–downstream relationship as a partial ordering. Within each region the allocation of resources may be represented as a linear programming problem, with a range of activities varying in the gross margins they yield and the intensity of water use required. Yields are affected by salinity, usually through a simple linear relationship based on the work of Maas and Hoffman (1977). In some cases, urban water use in Adelaide is also modelled.

The link between regions arises from the fact that water use upstream affects the availability and quality of water downstream. Quiggin (1988a) compared the solution arising when the linear programming problems in each region were solved sequentially to maximise surplus in each region, with the dynamic programming solution which maximises surplus for the river system as a whole. Quiggin characterises the first solution as an ‘open access’ solution and the second solution as a ‘common property’ solution.

The difference between the common property solution and the open access solution represents the social loss associated with the upstream–downstream externality. This loss includes not only damage caused by salinity but production opportunities foregone because of salinity and reduced water availability. Various methods of internalising this externality have been considered. Quiggin (1988a) considers the effect of higher water prices, incorporating an implicit Pigovian tax. Hall, Poulter and Curtotti (1993) examine the impact of making water rights tradeable. Both approaches yield significant welfare improvements.

The model analysed by Quiggin (1988a) is very simple, consisting of six regions and four crops, and is characterised as ‘illustrative’ rather than as a detailed representation. Subsequent work has extended this simple model in various ways. Hall, Poulter and Curtotti (1993) model more regions and crops and include market supply and demand. Sappideen (pers. Comm.) has developed a dynamic model with monthly steps in place of the once-off annual model of Quiggin (1998a). Quiggin (2000) extends the technology to allow for water-saving technology and state-contingent production under uncertainty, based on the approach developed by Chambers and Quiggin (2000).

### *3.3 Sustainability*

Much public discussion of environmental issues focuses on the notion of sustainability. So many different definitions of sustainability have been offered that discussion of the issue is inevitably confused. However, much of the intuition behind the term is derived from simple models of sustainable yield, derived from biological and economic analysis of fisheries and forestry.

Analysis based on this intuition has proceeded in two quite different directions. The first approach is to treat sustainability as a property of growth paths for the economy as a whole. The resulting analysis may be contrasted with 'old growth theory' (Solow 1956) in which natural resources did not play an important role.

Theoretical analysis of sustainability and growth begins with the proposition that the interests of future generations should be given equal weight with our own in making decisions affecting the long term future. This proposition was taken as axiomatic by Ramsey (1928) in deriving his savings rule, but was dropped in most of the literature on 'old growth theory'. Since this literature focused almost exclusively on the case of rising living standards, the fact that future benefits are discounted merely implies a slower rate of improvement. However, if the prospect that environmental degradation could lead to lower living standards in future is taken seriously, the idea that the welfare of future generations should be discounted appears inequitable, since it implies support for redistribution from low-income future generations to the higher-income present generation.

In the absence of inherent discounting of utility, the discount rate (at any point an optimal growth path) is endogenously determined by the rate of technological progress and the intertemporal elasticity of substitution (Howarth 1991, Howarth and Norgaard 1990). The discount rate is that given by the Ramsey 'golden rule'

$$\eta \, \dot{C}_t = Y_K/K_t,$$

where:

$C_t$ is consumption at time $t$

$Y_t$ is output

$K_t$ is the capital stock.

$\eta = -U''(C_t)C_t/U'(C_t)$ is a measure of aversion to intertemporal variations in consumption. Thus, provided the rate of technological progress is positive, the discount rate will also be positive.

Concern about environmental degradation is reflected in the assumption that capital, that is, technology embodied in produced goods, cannot be substituted indefinitely for natural resources, taken broadly to include all the contributions of the natural environment to human welfare, and agricultural production in particular (Hartwick 1977). In the absence of substitution opportunities, it may be appropriate to apply one discount rate to environmental goods and another to produced goods. In particular, if deteriorating stocks of natural resources coexist with general technological progress, the optimal discount rate for natural resources may be negative or zero even though the general discount rate is positive.

Similar results may, however, be obtained without the need for separate discount rates by projecting steadily rising relative prices for environmental goods. Dasgupta and Maler (1990) argue that all of the concerns addressed by sustainability theorists can be addressed more appropriately in the analysis of the present value Hamiltonian arising from the solution to an optimal growth problem.

Attempts to derive general principles from sustainability theory lead naturally to the conclusion that unsustainable practices arise as the result of an inappropriate choice of marginal discount rates (Quiggin 1997). Intensive agricultural industries based on irrigation have encountered sustainability problems relating to salinity, siltation and waterlogging. In these cases, the general approach to sustainability based on reducing the rate of discount of future environmental benefits appears appropriate.

The second direction of development of the concept of sustainability has been a search for specific sustainability rules analogous to the sustainable catch rule for fisheries. Within this framework, specific practices may be classed as 'sustainable' or 'unsustainable', according to whether they satisfy the sustainability rule. A variety of sustainability rules are discussed by Barbier (1987) and Barbier, Markandya and Pearce (1990). The sustainability rule approach works best in the case of activities, like fisheries, that are dependent on a specific local stock of natural capital.

In the case of irrigated agriculture, the most important stock of natural capital is the river system and the associated watersheds. Degradation of the stock of natural capital is reflected in rising water tables, reduced river flows and higher levels of salinity. Hence, a sustainable set of practices is one that ensures that the river system will be stabilised at an acceptable level of salinity, water quality and water flow.

## 4. Policy responses to environmental problems

Before the 1980s, most policy responses to the environmental problems of the Murray–Darling Basin involved local measures designed to mitigate problems of salinity and waterlogging in individual catchments. This local approach has gradually been subordinated to Basin-wide concerns about the sustainability and economic efficiency of practices regarding water use and land clearance in Australian agriculture, concerns which have focused particularly on the problems of the Murray–Darling Basin. These concerns have been reflected in the development of policies limiting tree clearance and the diversion of water for irrigation.

An analysis of recent developments in environmental management must be informed both by the theoretical frameworks described above and by consideration of the institutions of the Australian federal system. The starting point of the policy process has been the determination of desired limits on tree clearance and water diversion based on sustainability criteria. The attempt to satisfy these criteria has been based on a combination of direct regulation, pricing policies justified primarily in terms of Pigovian welfare theory, and attempts to create markets for appropriately defined property rights. These policies may usefully be analysed in terms of the interaction between private and common property rights and of the determination of prices that take appropriate account of externalities.

*4.1 Tree clearance and dryland salinity*

The problem of dryland salinity raises problems of non-reciprocal externality. Farmers clearing trees from recharge areas may impose externalities on others whose land consists largely of discharge areas. In principle, these issues could be addressed through Pigovian taxes, as proposed by Greig and Devonshire (1981). In practice, however, no policy proposals of this kind have been considered. Hence, as is commonly the case, externality concepts are of more value in understanding the problem than in designing policy responses.

The sustainability framework is also helpful in understanding the problem. Fisher (1995) discusses the difficulties of farmers facing the financial pressures of low commodity prices, for whom there appears to be little alternative to farming practices that will, in the long run, increase salinity and reduce the value of their own property, as well as that of neighbouring farmers. Farmers in financial difficulty face high effective discount rates, and are therefore more likely to adopt unsustainable farming practices (Blyth and Kirby 1984; Quiggin 1987).

Responses to the perceived unsustainability of land management practices and particularly tree clearance have taken two main forms. First, most states have imposed restrictions on tree clearance. Second, there have been attempts to promote sustainable practices through cooperative programs such as Landcare.

Restrictions on tree clearance represent an attenuation of the rights of landholders who previously had unrestricted rights to clear their property. Compensation has been paid in some, but not all, cases. Proposals for restrictions on tree clearance in Queensland, motivated primarily by concerns about biodiversity and greenhouse gas emissions, are currently (August 2000) the subject of debate between the Commonwealth and State governments regarding compensation. In anticipation of such restrictions, the rate of tree clearance has increased.

Hodge (1982) analysed the case for the creation of private property rights to cleared land, and an associated market in which such rights could be traded. The basic argument is familiar. Assuming that the socially optimal area of cleared land has been determined, the market in rights to cleared land will ensure that such rights are allocated to those who value them most highly, thereby achieving any given reduction in land clearance at minimum social cost. Quiggin (1986) extended this analysis, arguing that, in the presence of uncertainty about optimal cleared areas, common property institutions for catchment management would be required in addition to private rights to cleared land.

### *4.2 Sustainability and the Cap*

The decision of the Murray–Darling Basin Ministerial Council in 1995 to impose a Cap on water usage in the Basin was the crucial event in the move from an expansionary water economy to a mature water economy. The imposition of the Cap was a response to evidence that the existing policy framework was unsustainable.

In one sense, the unsustainability of existing policies is self-evident. As shown in Figure 1, if entitlements existing in 1995 were fully developed by 2020, as was predicted in the absence of policy change, more than 90 per cent of the average natural flow to the sea would be diverted annually.

A more difficult problem is to assess the extent to which diversion levels and irrigation practices are unsustainable, in the sense that, at the margin, the costs of the long-term damage they generate outweigh the benefits of additional agricultural output. Until quite recently, there was no clear evidence that overall salinity levels in the rivers of the Murray–Darling Basin had increased over time; rather, they seemed to have remained "relatively constant" (Meacham 1984). However, this is no longer the case, with studies now showing that salinity levels are rising significantly in most rivers in the Basin (Williamson et al. 1997), except where remedial actions have been undertaken.

The Murray–Darling Basin Ministerial Council (2000) estimates the costs associated with salinity at $46 million per year. This amount is relatively modest compared to aggregate gross margins of the order of $1 billion per year. However, maintenance of existing policies is likely to lead to higher salinity and higher costs. Moreover, Quiggin (1998b) argues that estimates of costs actually incurred fail to capture the full reduction in welfare associated with externalities.

The issue is further complicated by the fact that, in the absence of cost-reflective prices and smoothly functioning markets for water rights, water is not, in general, allocated to the use that will generate the highest benefit. Hence, there is no unique and well-defined measure of the marginal benefits of additional agricultural output. It follows that an appropriate analysis of sustainability must take account of property rights and externality considerations.

*4.3 Private property rights*

The private property rights approach yields a range of useful insights into the problems of the Murray-Darling system. Brennan and Scoccimaro (1999) apply the private property rights approach in considering the development of water markets.

During the expansionary phase of the water economy in the Murray-Darling system, individual irrigators obtained a variety of private rights to use water. Rights were typically unlimited in duration, either explicitly or because they were based on licenses that were renewed automatically.

However, rights were attenuated in various ways. First, they were not, in general, tradeable, except through the sale of the land to which they were attached. Second, they were contingent on the availability of adequate water. Third, the value of existing rights was limited by the relative ease with which developers of new irrigation areas could obtain water allocations. Hence, the property rights regime had some of the characteristics of an open access resource.

There were some moves towards tradability of rights during the 1980s and early 1990s (Brennan and Scoccimaro 1999), but the crucial policy decision was the imposition of the Cap.[2] In part, this decision involved restrictions on the use of water rights, thereby attenuating the private property rights of individual users. However, the imposition of the Cap implied that, in future, no net creation of new private water rights would be permitted. The effect, therefore was to raise the value of existing rights, to the extent that such rights were preserved after the imposition of the Cap. Moreover, the imposition of the Cap was accompanied by an increase in the tradeability of rights, which also enhanced

[2] South Australia had already restricted the issue of new licenses, but the crucial problems of over-allocation were in the upstream states affected by the Cap. A partial moratorium on new licenses in New South Wales proved ineffective because of existing overallocation.

their value. Although water rights have not been fully detached from land, and trading of water rights remains limited, trade is likely to grow in future.

Since existing rights exceeded appropriations and the Cap precluded any increase in appropriations (and foreshadowed the possibility of reductions in total appropriations), the imposition of the Cap implied some net withdrawal of rights. The approach recommended by the Independent Audit Group (1996), and adopted by the states in their implementation of the Cap, was to create a hierarchy of rights.

The hierarchy proposed by the Independent Audit Group (1996) is a lexicographic ordering in which rights are ordered by their legal status, then by history of use, with rights of a given legal status being ranked higher if there is a history of use. The legal categories are subdivided on the basis of the existence or absence of a history of use, leading to a system of six categories:

(1) statutory rights with a history of use

(2) 'sleeper' statutory rights with no history of

(3) non-statutory rights with a history of use

(4) non-statutory rights with no history of use

(5) formal promises of future access; and

(6) expectations of access based on past practices.

'Sleeper' rights (rights allocated to particular blocks of land, but never used) fall into category 2, while the used and unused components of 'dozer' rights (partially unused rights) are allocated to categories 1 and 2 respectively.

All rights with a history of usage as of 1993-4 fall into categories 1 and 3. It follows, given the existence of 'sleeper' and 'dozer' rights, and some rights created after 1993-4, that the total rights allocated under categories 1, 2 and 3 must equal or exceed the Cap. Hence, the total allocation of rights in categories 1, 2 and 3 must be reduced before any rights in categories 4, 5 and 6 can be converted into access.

There are a variety of ways in which the requirements of the Cap could be met. First, technological improvements could reduce losses of water through evaporation and absorption in channels, thereby permitting a smaller aggregate diversion of water to satisfy a given set of rights to water use. Second, some existing rights could be purchased from their holders. Third, rights with a limited duration could be withdrawn or downgraded at the expiration of their term, rather than being automatically renewed in line with past practice. Finally, an 'efficiency dividend' could be imposed on holders of rights. This would take the form of a proportional reduction in allocations based on an assessment of the average reduction in water consumption that would be associated with the adoption of 'best practice' technology in on-farm water use.

A noteworthy feature of the Independent Audit Group's approach is that 'sleeper' and 'dozer' statutory rights rank ahead of less formal rights with a history of use, even though irrigators may have come to rely on the latter rights. The alternative of giving a lower ranking to inactive rights has obvious political advantages, since those from whom rights are withdrawn do not suffer any actual loss of income, though they lose potential future benefits. Assuming that rights are not perfectly tradeable, there are also efficiency advantages. In general, the fact that rights are not being used indicates that the use for which they are allocated is of low value. Hence, the social cost of withdrawing these rights is low.

However, the uncompensated withdrawal of statutory rights is a violation of the general norm that property rights should be secure, and may be seen as reducing the value of property rights in general. An additional difficulty with placing a high weight on a history of usage is that, if anticipated, this approach creates 'use it or lose it' incentives, leading holders of rights to exercise them even when the costs of doing so exceed the benefits.

A closely related set of issues arises from proposals to restore some proportion of the flows previously diverted from the Snowy River. Restoration of flows to the Snowy River implies a reduction of flows to the Murray and Murrumbidgee Rivers and hence either a reduction in diversions or a reduction in the residual flow in those rivers. A reduction in diversions must be achieved by one of the methods considered above.

The difficulties associated with the interaction between private rights to water use and common rights over catchments and the Basin as a whole are most acute in New South Wales. Water use in Queensland has been growing rapidly, but from a low base. South Australia has historically adopted a conservative allocation policy, with the result that existing statutory rights can be accommodated within the Cap. In Victoria there has been modest over-allocation, in the sense that, under existing patterns of water use, not all rights could be exercised in years of very low flow.

In New South Wales, by contrast, over-allocation has been routine. As a result, even category 1 rights cannot be fully exercised in low-flow years. Moreover, the ratio of 'sleeper' and 'dozer' rights to active statutory rights is high. Moreover, there are increasing diversions of water by riparian users on unregulated tributaries (those not controlled by dams and weirs) and increasing capture of surface water through farm dams.

Given this background, a move to tradability of New South Wales water rights without some withdrawal of existing rights would lead to allocations far in excess of the Cap, and, in many cases, in excess of the maximum physical capacity of catchments. These issues are discussed further in Department of Land and Water Conservation (NSW) (1998). Further issues regarding tradeability are discussed by Crase, O'Reilly and Dollery (2000).

The policy response in New South Wales has culminated in the *Water Management Bill* 2000 introduced in June 2000. The Bill incorporates explicit recognition of environmental externalities for the first time, and is based on sustainability considerations, particularly the principle that flows needed to restore adequate river health should have a prior right over the provision of water for consumptive use.

However, the main focus is on defining private property rights in a way that is consistent with total availability of water and efficient resource use. Except for a limited domestic use and stock allowance, riparian rights over unregulated rivers are replaced by a system of three categories of water entitlements available under conditions of low, medium and high flow. In general, water rights over regulated rivers are converted from volumetric entitlements to shares in the available flow. However, in periods of severe water shortage, high security users, including urban water supplies, power companies and some growers permanent crops such as vines and fruit trees will have priority over irrigators with general security (NSW Department of Land and Water Conservation 1999)

*4.4 The role of common property*

The effect of combining regional management of aggregate water use in each catchment with the expansion of trading rights is to create a mixture of private and common property rights. Such an approach is an optimal response to the problems of shared resources, such as catchments, where knowledge is imperfect.

In much of the property rights literature, the creation of a perfectly well-defined set of private property rights is assumed to be the ideal policy outcome. In the case of an irrigation system like that operating in the Murray–Darling Basin, a water property right might be specified as a contingent annual allocation depending on a detailed specification of the relevant states of the natural system, including initial levels of water storage, rainfall, temperature and stochastic occurrences like algal outbreaks. Given such a detailed specification of the possible events, there would be no need for further intervention once the rights had been created and the market established. Equally, however, given such detailed knowledge and a specification of the demand function, it would be possible for a central manager to determine the optimal allocations of water directly.

In the real world of imperfect knowledge, the dilemma observed by Randall (1983) is inescapable. A system of property rights must be flexible enough to permit adjustment in the light of new knowledge, but this means that individual rights cannot be perfectly specified. Quiggin (1988b) argues that the appropriate response to this problem is the creation of common property rights which create a framework within which the private property rights of individual resource users may be constrained and modified.

Dudley (1992) proposes an alternative response to the common property problem, based on the idea of capacity sharing. Rather than annual entitlements to water, individuals would receive rights to a certain proportion of the capacity in a given storage. At their discretion, they could call for a release of capacity and a corresponding delivery of water. The storage could be managed collectively by the owners or by a private or public corporation.

Recognition of the common property aspects of the Murray–Darling Basin is most evident in the Integrated Catchment Management Framework (Murray–Darling Basin Commission 2000c),which

> ‘will identify targets that are needed for the Basin, such as water quality and river health. These targets will help ensure that key assets in each catchment and in the whole Basin, such as wetlands, native vegetation, built infrastructure, recreational areas, cultural sites, high quality drinking water and productive land, are protected. This will mean, for example, setting targets for the levels of salinity in the water flowing out the end of major valleys. Local communities, industries and governments, working together, will need to decide what assets in each

> catchment should be protected, and then make sure the necessary action is taken over future years to prevent river salinity levels rising above the target. '

This approach, which implies the effective creation of common property rights, is embodied in the *Water Management Bill* 2000 in New South Wales.

*4.5 Externalities and prices*

Where users appropriated water directly from the river system, it was typically unpriced. Users supplied by publicly-operated irrigation schemes paid for their water, but water prices rarely covered all operational costs and included no charge for the capital cost of the scheme or for the value of water.

Changes to water pricing have resulted primarily from the COAG agreements which require water suppliers to charge full-cost prices and eliminate cross-subsidies. In general, the 'full-cost' price has not included any allowance for the opportunity cost of water or for externalities such as salinity (the resource abstraction charge imposed in the Australian Capital Territory is an exception). However, political acceptance of prices covering the full cost of irrigation works may be regarded as reflecting a compromise between forces favouring continued subsidisation of irrigation and those favouring a higher price incorporating Pigovian taxes on externalities.

Nevertheless, the full implementation of a system of tradeable water rights will require the development of pricing systems that are consistent across state boundaries and that take appropriate account of externalities. This point is illustrated by the Pilot Interstate Water Trading Project which has required the formulation of appropriate exchange rates between upstream and downstream water use, taking account of the increased negative externalities arising when water use is transferred upstream. In the Pilot Project, the exchange rate between South Australia and the upstream states is 0.9. That is, rights to use 10ML of water in South Australia may be traded for rights to use

9ML in Victoria or New South Wales (Murray–Darling Basin Commission 2000d). The effect is the same as that of a Pigovian tax.

*4.6 The path ahead*

Economic considerations played a very limited role in policymaking during the expansionary phase of the water economy in the Murray–Darling Basin. As the expansionary phase drew to a close and the problems of the mature water economy became evident, the need for appropriate economic institutions became apparent. Indeed, there was some tendency to suggest that the resolution of the problems was a simple matter of getting prices right (or, from a Coasian perspective, creating clearly defined property rights).

The experience of the last decade has shown that appropriate economic institutions are essential, but that the complexity of the problem is such that no simple policy solution is likely to prove adequate. Concern about degradation of land, water and natural environments, particularly in relation to the Murray–Darling Basin, is becoming steadily more widespread. The environmental movement, in particular, is shifting its attention from the forest preservation issues that defined the environmental battles of the 1970s and 1980s to broader issues. Government responses to evidence of rural and regional disaffection with microeconomic reform has included a search for 'nation-building' responses to problems such as land degradation.

In these circumstances, the development of more sophisticated systems of pricing, regulation and property rights (private and common) is needed merely to keep pace with the growth of competing demands for control over land and water resources. The acceptance of sustainability criteria in the long run will require a reduction in total diversions of water and a return to a flow regime more similar to that which would occur naturally. Hence, significant improvements in the technical and allocative efficiency of water use will be needed simply to maintain current levels of irrigation-related agricultural output.

## Concluding comments

The convergence of agricultural economics, resource economics and environmental economics has been a notable development of the past twenty years, reflected in institutional changes such as the replacement of the *Australian Journal of Agricultural Economics* by the *Australian Journal of Agricultural and Resource Economics.*

The problems associated with irrigated agriculture in the Murray–Darling Basin involve complex interactions between agriculture, resources and the environment. The economic literature on the Murray–Darling Basin therefore provides an ideal illustration of the extent to which economic reasoning derived from a range of different perspectives can contribute to an understanding of environmental problems and to the development of appropriate policy responses.

Economists have long debated the relative merits of approaches based on externality, property rights and sustainability concepts. In understanding the complex problems of the Murray–Darling Basin, an eclectic approach drawing on all of these perspectives seems most appropriate.

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Figures: To be supplied in a format suitable for publication

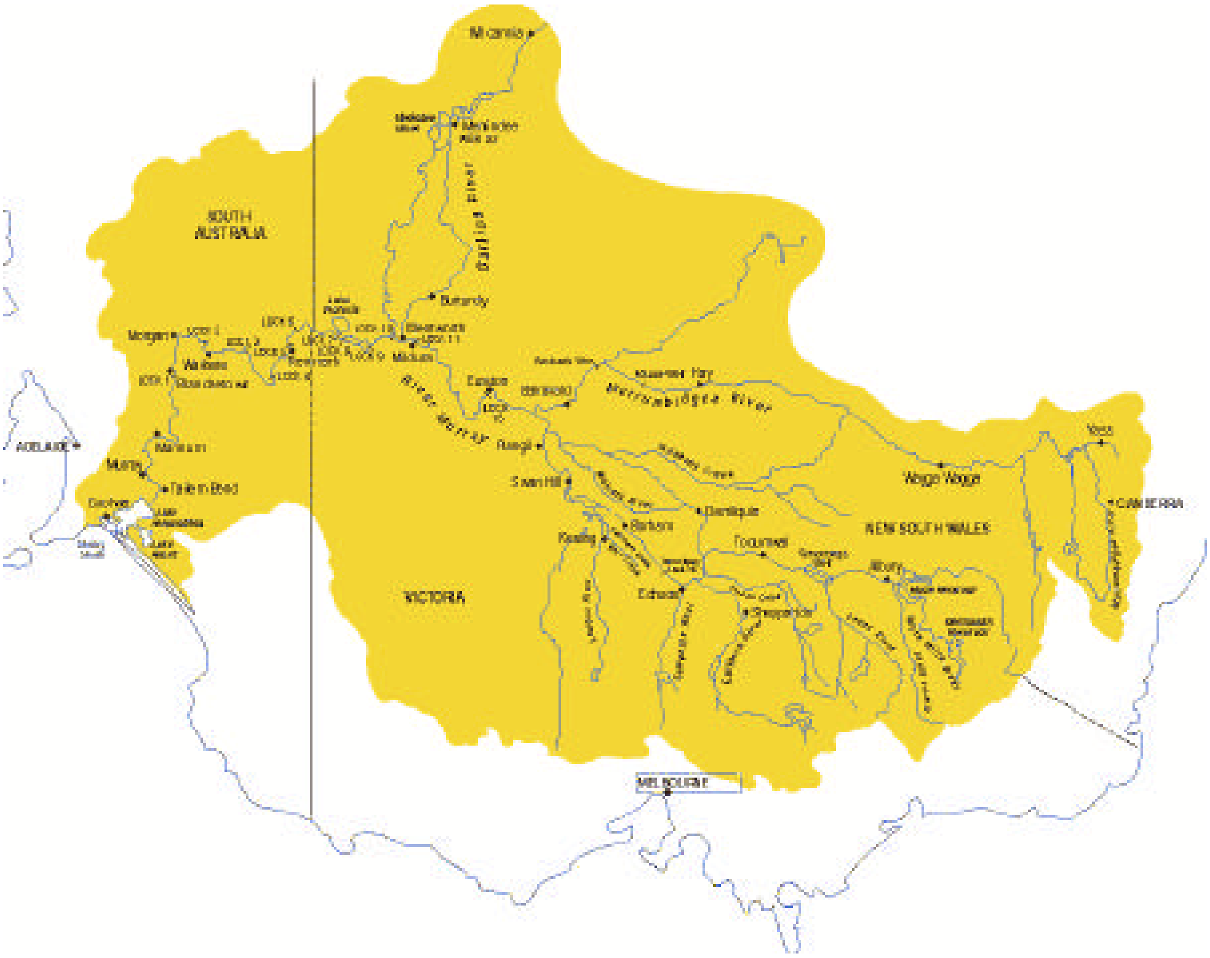


Figure 1: The River Murray and Lower Darling (Source: Murray-Darling Basin Commission)

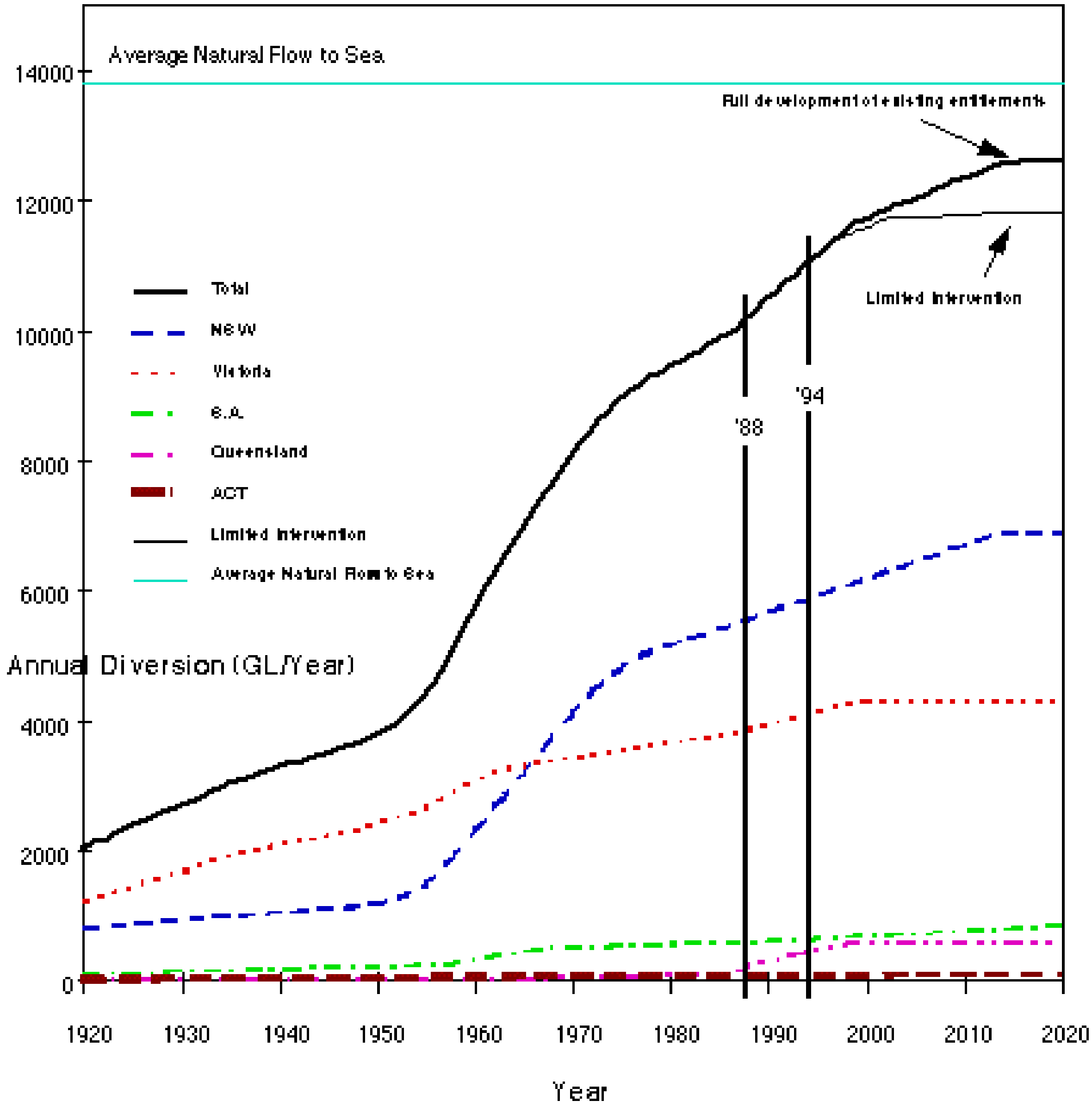


**Figure 2: Annual diversions from the Murray–Darling Basin 1920–95 with projections to 2020**

Source: Murray–Darling Basin Commission (2000)