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EFFICIENT WATER ALLOCATION IN A HETEROGENEOUS CATCHMENT SETTING

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CERTIFICATION OF ORIGINALITY

I hereby certify that the substance of the material used in this study has not been submitted already for any degree and is not currently being submitted for any other degree and that to the best of my knowledge any help received in preparing this thesis, and all reference material used, have been acknowledged.

Lisa Yu-Ting Lee
2007

ABSTRACT

Efficient Water Allocation in a Heterogeneous Catchment Setting

The problem of water scarcity has become one of the most controversial topics in Australia over the past decades, with particular focus being the 'sustainable' allocation of water between extractive and environmental purposes. Geographical factors are defining the extreme variability in climate and water supply in Australia and, in the past, this was used as a rationale for the construction of large irrigation projects to deliver water to rural, urban, and industrial users. During this 'expansionary' phase of Australia's water use sector, the cost of augmenting supply was relatively low and environmental considerations were secondary to the development imperative. As a result, water resources became over-allocated for extractive uses spurred on by consistent underpricing of water, which indicated a failure to reflect the true cost of water supply. As Australia's water economy entered a 'mature' phase, it was no longer possible to increase supply cheaply as the most easily accessible water resources had already been captured. This was followed by widespread environmental degradation manifested in the Murray-Darling Basin, the nation's largest river basin which hosts much of Australia's agricultural production. Consequently, the focus shifted towards demand management, leading to a myriad of regulation aimed at increasing the allocative efficiency of scarce water resources. Towards this end, substantial government funding was injected into the various initiatives throughout the water reform process.

Despite the on-going government activities in the area of water reform, the understanding of the actual economic impact and environmental outcomes of various water policies in practice remains limited. In the absence of such understanding, the effectiveness of various government water initiatives is ambiguous and inevitably compromised.

The present study addresses this knowledge gap by establishing a method for evaluating the economic and environmental outcomes of environmentally-oriented polices that affect irrigated industries in a catchment. The method is based on an integrated biophysical and economic modelling approach, which enables spatial relationships to be

captured accurately allowing a more realistic analysis. Information generated from a computer based biophysical simulation model form the basis of an economic optimisation model with constraints pertaining to environmental targets and water supply limits. The economic model consists of a linear programming and dynamic programming component, and involves the optimisation of resource use from a catchment manager's perspective, seeking to achieve efficient resource use but at the same time conform to given environmental objectives. This two-stage modelling process was required to determine the optimal intra-seasonal and inter-seasonal water allocation, given various catchment environmental targets. The interdisciplinary approach enables the economic and ecological outcomes of the catchment management policies to be simulated and assessed at a spatially explicit scale, due to the link to Geographical Information Systems (GIS) in the biophysical model.

The overall objective was to create a decision-making framework that could be used to determine the least-cost means of meeting environmental targets and resource constraints. The solutions to the analysis are directly applicable to the case study, the Mooki catchment in northern New South Wales (NSW), but with an adaptable framework that can be applied to other catchments. Specific objectives include an evaluation of the possibility of using alternative irrigation systems, as well as an evaluation of the benefits that can be realised by establishing water market, in the light of environmentally-oriented catchment policies for the case study. The economic cost of achieving environmental targets pertaining to environmental flow requirements and salinity reduction, in the form of end-of-valley salinity targets, was explicitly calculated through the economic model.

While salinity targets have been set for NSW catchments, the practicality of such targets is in question, given the substantial reductions in water allocation to irrigation activities, which is one of the key contributors to deep-drainage. An additional objective in this study was therefore to investigate the value of having deep drainage targets. A further consideration is the effect of "external agents" in the form of government plans to buy-back entitlements from irrigation districts, or the possibility of significant water rights purchases from mining industries. The implications of external water market entrants on the regional agricultural industry were examined.

Some conclusions and recommendations drawn from the results of this thesis are as follows:

- Alternative irrigation systems, including pivot and drip irrigation, are beneficial to irrigators in the Mooki basin, improving their water use efficiency and productivity. Pivot irrigation systems were shown to be the optimal system for most of the catchment, while drip irrigation systems are less economically viable due to the high cost of investment. Significantly, the viability of these irrigation systems is reliant on the security of water supply. It has been demonstrated that where groundwater is used in conjunction with pivot or drip, profit is consistently higher compared to where surface water is used. This relates to the uncertainty of river flow in an ephemeral system, which result in irregular irrigation water availability and, consequently, lower crop yields. To encourage investment in water efficient technologies, it is important there are ample and secure water supplies. Considering the recent cuts in groundwater entitlements in the Mooki basin, and the prospect of future reductions in both surface and ground water rights, irrigators in the region may be reluctant to make the investment. This is especially the case where the capital requirement for water efficient technologies is substantial. It reiterates the importance of secure water rights and clear policy implications for future supplies.
- It was found that the initial area-based water licensing led to an inefficient distribution of water amongst irrigators, and that a fully functional water market would enhance basin profitability since water is shifted to higher value uses in the downstream-most region of the Mooki. This leads to an efficient outcome, as irrigation areas contract and leaves more land available for conservation purposes. The presence of a water market also augments the value of irrigation technologies, leading to a shift away from tradition furrow irrigation towards pivot irrigation systems. In this light, it would be more effective for government

funding to be used in promoting water trade than subsidising the cost of irrigation technologies.

- The opportunity costs of meeting environmental flow and salinity reduction targets are also reduced where water efficient technologies and water trading are utilised. However, where these environmental targets are stringent, the economic burden will be substantial even if water trading or irrigation technologies are used. Where a significant reallocation of water for environmental flows or reduction in salinity is envisaged, the resulting opportunity costs should ideally be justified by the environmental benefits that are generated.
- A dual-instrument, simultaneously managing water use and deep drainage through separate instruments, is unnecessary. Surface water caps alone provide sufficient conservation signals to reduce unproductive water losses to deep drainage. If drainage is not at a critical level (i.e. not excessively contributing to salinity) then it is more efficient to impose caps on surface water, which have the added benefit of increased environmental flows. Furthermore, (surface) water caps do not affect groundwater use, which have recently been cut to 'sustainable' extraction rates. This is preferable to imposing additional salinity caps which will cause groundwater use to fall below sustainable extraction levels, and are likely to generate excessive administrative costs. Also, given the difficulty and cost associated with deep drainage measurement, the economic cost for setting a 'wrong' target will also be high.
- The economic impact of an external agent competing for water in the regional water market is not expected to be significant. The volume of water that is demanded by a hypothetical coal mine in the catchment represent a relatively small portion of surface water supply available to the irrigators. The effect on the regional agricultural industry is also fairly small compared to the value that the water represents to the coalmine. While the general conclusion is that there is a net benefit to permitting external buyers to enter the water market, other indirect effects such as employment or environmental impacts have not been factored into the analysis. These considerations would form a valuable extension in future research.

This thesis represents one of few bio-economic studies that can provide spatially-referenced solutions in an Australian context, through the combined use of a GIS-integrated biophysical and economic model. The ultimate intention is to demonstrate the value of developing a streamlined, interdisciplinary framework that utilises the power of GIS, to enhance the efficiency of natural resource management and lead to a socially optimal outcome.

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Lisa Yu-Ting Lee
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Chapter 1.

INTRODUCTION

Vigorous debate surrounding the efficient use of water resources has been taking place in Australia in recent years, stimulated by the prolonged drought conditions and increasing focus on environmental value of water. At the centre of the debate over water management is the Murray-Darling Basin (MDB), regarded as Australia's food bowl that produces over 41% of Australia's agricultural output. The importance of the basin is highlighted by the fact that the majority of all water use in Australia is consumed in the MDB, with almost 90% of the system's water diverted for extractive uses (CRCIF 2005; DAFF 2006). Numerous water policies have been implemented since the 1994 Council of Australian Governments (COAG) reform, in recognition of inefficient water allocation between extractive and non-extractive uses. However, there is great uncertainty surrounding the various strategies to improve irrigation efficiency from both ecological and economic standpoints. The aim of this research is to propose a method that can be used to determine the economic impact of various environmental policies, and the way that these policies can be achieved at least cost. The method is showcased on a case-specific basis using spatially explicit information.

The problem of the misallocation of water resources can be largely attributed to the long period during which water was underpriced in Australia. This was driven by the early expansionary phase, where irrigation development was subsidised which resulted in irrigation water never being priced at its full cost (Randall 1981a; Davidson 1969). Consequently, excessive water diversion has led to severe degradation of the riverine environment, as well as raising groundwater tables, resulting in secondary salinity and salt scalds on agricultural land. While it is important to limit the environmental degradation resulting from the inefficient allocation of water resources, it is also important that proposed measures towards better water management generate maximum net social benefits. This may be achieved by shifting inefficiently used water resources from irrigation to where it has greater value, which may be in other sectors of the economy or in the environment. Water markets have been relied upon to achieve such an efficient reallocation, and have been introduced in most catchments in New South Wales (NSW). This was done in conjunction with Water Sharing Plans, which stipulate a set of extraction rules and minimum environmental flow requirements. In addition, the Murray-Darling Basin Commission (MDBC) has implemented a Salinity Management Strategy to control salt loads entering the Murray-Darling from various parts of the Basin. The Federal government has also recently announced a National Water Plan to buy-back entitlements to provide for environmental flows, as well as to support investment in water efficient technologies on-farm.

However, while there is much discussion in the literature pertaining to the efficient allocation of water on a catchment scale (Heady and Hall 1968; Beare et al. 1998; Bernardo et al. 1987; Zilberman et al. 1991; Tsur and Dinar 1995; Bjornlund 2003b; Freebairn 2005; Heaney and Beare 2001; and others), empirical work to assess the cost of various environmental targets and to determine the least-cost means of achieving these objectives seem to be lacking. There is considerable pressure for irrigation industries to improve water use efficiency and improve their environmental record, and yet the effects of the various measures in this direction on the economic performance of the affected industries, are unclear. To meet these challenges irrigators need to make optimal decisions about crop production, source of irrigation water, land allocation, and in particular the use of water efficient irrigation technologies which require substantial capital investment. Furthermore, the effects of the functioning water market in relation to the abovementioned aspects have yet to be fully understood in an empirical setting. The increasing competition that irrigators are facing from other industries, most notably the mining industry (Strang 2006) has also become an additional challenge in recent times.

This research therefore aims to develop an empirical method that can be used to determine the optimal choices that should be made at a farm and catchment level in relation to a number of control variables (crop choice, water use, irrigation systems, water trade, etc.), so that the economic objectives (e.g. profit maximisation) are achieved, but at the same time the outcomes are conforming to the environmental imperatives of the community. Particular environmental concerns addressed in this research are in relation to environmental flow provisions and salinity targets. The research approaches the problem by using an interdisciplinary framework, including a Geographical Information System (GIS) based biophysical model such that the results are directly applicable to the study area but flexible enough to be transferred to other catchments.

This integrated framework is used to evaluate a number of research questions pertaining to the effectiveness of various policies targeted towards improving environmental outcomes in a catchment with a substantial irrigated agriculture industry, as well as the impact of increased competition for water from other uses and sectors. As part of the analysis, the value of a fully-functioning water market within a case study irrigation district will be investigated, with the key research questions being the impact of water trading on the regional economy and its role in achieving environmental targets at the least-cost.

Another facet to explore is the value of using policy instruments designed to control salinity in conjunction with policy instruments designed to control the quantity of water diverted from the river systems. While salinity standards have been set for NSW catchments as part of the MDB Salinity Management Strategy, the practicality of a widespread salinity capping scheme is questionable, given the difficulty and cost associated with measuring diffuse sources of salinity across a large landscape. Due to the conjunctive nature of water use and deep drainage (water lost to the soil profile in irrigation, contributing to salinity), there is also the possibility of duplicating administrative costs with little net benefit to environmental objectives. There is the need to assess the capacity of policies that target deep drainage to achieve salinity mitigation, and thereby evaluate the need for a separate policy instrument to manage deep drainage occurrence. An objective of this research is to look at the economic viability of introducing a separate target to contend with salinity, through the imposition of a salinity, or deep-drainage cap.

The impact of future reduced water allocations may be confounded by increasing competition for water. Substantial competition for the basin's irrigation industry may arise from the entry of external buyers into the regional water market, which has significant implications for the regional agriculture. This comes amidst discussions of government buy-backs of entitlements for environmental flows, as part of the Commonwealth Plan for National Water Security (Howard 2007), and the possibility of an expansion of coal mining, a water intensive industry, in the northern region of NSW. This has instigated considerable community debate pertaining to environmental concerns as well as competition for infrastructure and water, given plans to substantially reduce surface and groundwater entitlements over the next five to ten years. The potential effect of the presence of an external water buyer in a catchment, personified by a hypothetical coal mine, on optimal water allocation in the catchment where a functioning water market exist is another research question addressed in this thesis.

1.1 RESEARCH OBJECTIVES

In this research, the overall aim is to develop a decision-making framework that can be used to determine the production pattern in the basin which allows efficient irrigators to maintain profitability, but simultaneously conform to water sustainability targets and environmental objectives of the community. The framework involves a combined economic and GIS-based hydrological modelling of production activities on a catchment level, enabling a spatially explicit analysis of production and resource use. Modelling at a catchment scale allows for an analysis that readily incorporates the social values of water, allowing the optimal spatial distribution of resources and agricultural activities to be determined. Specific objectives of this research are:

1. To apply the GIS-based decision-making framework to the case study basin, and thereby construct a resource management framework that is transferable to other catchments;
2. To determine optimal spatial choice of alternative irrigation systems in a catchment, in the face of tightening environmental targets;

3. To evaluate the improvement in allocative efficiency brought about by a fully-functioning water market in the case study region;
4. To determine the value of dual policy instruments (deep drainage target and environmental water flow target) to control environmental outcomes in a catchment. Deep drainage has serious environmental consequences in terms of increased groundwater and soil salinity, and potential water logging. While it is important to reduce deep drainage, it is important to evaluate the efficacy of creating a separate instrument to manage its occurrence;
5. To assess the potential impact of a significant industrial water user participating in the regional water market, on the regional agricultural industry. This can correspond to either Government buy-back of entitlements or to an entry of a water-intensive mining industry in the catchment.

1.2 RESEARCH APPROACH

The research approach in this thesis has been to conduct a spatially explicit analysis of optimal decisions in spatially referenced irrigation enterprises. This is in contrast to the representative farm approach, which has been extensively used in economic analyses (Aluwihare et al. 2005; CARE 2003; Letcher and Jakeman 2002; and others). The representative farm approach, which typically utilises average values for parameters of interest (e.g. deep drainage, crop yield, irrigation, etc.) in effect analyses inherently heterogeneous landscapes by imposing assumptions of homogeneity. While this approach reduces the complexity involved and can usefully shed light on some important phenomena, it can result in misleading conclusions which lead to blanket policies that are costly and ineffective, because they do not take into account the differentiated nature of catchments.

In contrast to this, the parameters of interest in this thesis are treated on a site-specific basis and at a high level of spatial detail. This is achieved through the use of a GIS based biophysical computerised simulation model. The model was applied on the Mooki River catchment, because of data availability and biophysical modelling expertise.

Nevertheless, the theoretical and methodological approaches are flexible enough to be implemented, with minor adjustments, to other catchments or regions.

A summary of the steps undertaken in this thesis is as follows:

1. An overview of the current water situation and reform process in Australia is conducted, with more detailed inquiry into the New South Wales (NSW) water policies, in particular those relating to the case study catchment. The aim is to determine the changes pertaining to water allocations that affect irrigators in the region;
2. Simulations are run in the hydrologic-biophysical model, the Soil and Water Assessment Tool (SWAT), which was set up with parameters specific to the catchment. The SWAT uses historic climate data including rainfall and river flow to simulate agronomic and hydrologic variables, depending on the production activities specified. Simulations were run under various scenarios with different production parameters, and the output from the simulations are used as data input for the economic model;
3. An economic model was developed based on the data from SWAT, and was set up as a dynamic optimisation model through a finite time horizon. For each time period, a separate optimisation model was solved in the form of a linear programming model integrated with an intra-regional water trade model. The periods were linked by resource constraints and limits on the volume of extraction in each period. This is based on the current water reform policies for the Mooki Basin. Three different treatments were analysed, each with different levels of choice variables available, including alternative irrigation systems (AIS) and water trading.
4. Alternative scenarios were run within each treatment, with parameterised environmental flow requirements, salinity caps, water market prices, and the possibility of an external agent entering the regional water market. Resource allocation under each scenario was driven by the optimisation objective in the economic model, given the constraints on resources.

5. Inferences are drawn from the results of the various scenarios and treatments, and recommendations made regarding water resource management towards the socially optimal outcome. The recommendations are made in line with the economic efficiency criteria to shed light on the efficacy of various environmental policies, and how the policy objectives can be achieved at the least-cost.

1.3 OUTLINE OF THESIS

This thesis is comprised of nine chapters. Chapter 1 introduced the reader to the research question and the approach taken. Chapter 2 provides a review of the current situation with water allocation and use in Australia, and some historical notes on the evolution of the problem. In Chapter 3, the institutional arrangement for water management in the Australian context is presented, in order to introduce the various environmental policies relevant to this thesis. Chapter 4 provides a review of literature pertaining to water economics, which highlights the complexity involved in managing this important natural resource. Chapter 5 outlines the economic theory to resource allocation, which underpins the operation of the economic model used in this thesis. In Chapter 6, a description of the case study basin, the Mooki, and the various characteristics specific to this basin are presented. Chapter 7 presents the specific economic model used for this thesis, as well as the integrated approach and utilised data. The results from the model simulations are discussed in Chapter 8. The ultimate Chapter 9 summarises the research findings and provides some conclusions, policy implications, limitations and directions for further research work.

Chapter 2.

BACKGROUND OF WATER USE IN AUSTRALIA

The water supply situation in Australia underpins the distributional problems at the crux of the nation's water management debate. A review of the geographical features that dictate the aridity of Australia's landscape, and the ensuing problems of water supply, is provided in this chapter. The transition between the developmental and mature phase of Australia's water economy is also reviewed, with reference to the range of government initiatives aimed at rectifying the resource allocation problem throughout this period.

2.1 STATE OF WATER RESOURCES IN AUSTRALIA

Australia is regarded as the driest inhabited continent on earth, with the lowest runoff to precipitation ratio compared to other continents (Haisman 2005). However, on a per capita basis Australia is no drier than other countries, with large areas of well-watered land. In this light, water scarcity can be attributed to the extreme variability in water resources both spatially and temporally. More than one-third of Australia produces no surface runoff at all, with 60% of runoff occurring north of the Tropic of Capricorn and the rest being concentrated in Tasmania (Pigram 1986). The continent's spatial variability in rainfall is reflected by the fact that floods and droughts are the most frequently occurring natural disasters. The distribution of freshwater runoff in Australia is illustrated in Figure 2.1.

A number of factors contribute to Australia's aridity. Firstly, the continent is characterised by a flat landscape, the most distinctive topographic feature being the Great Dividing Range along the eastern and south-eastern coastline. Orographic lifting of moist air over the mountain ranges results in greater precipitation along the coast but leaves arid conditions inland. Secondly, evaporation is very high; on average 87% of all moisture is lost to evaporation compared to 60% occurring in North America and Europe. Although the rate of evaporation is variable across the landscape, only a small proportion of rainfall becomes surface runoff, much of which flows out to sea. The moisture is evaporated or transpired by vegetation, with the excess seeping underground (AWRC 1975).

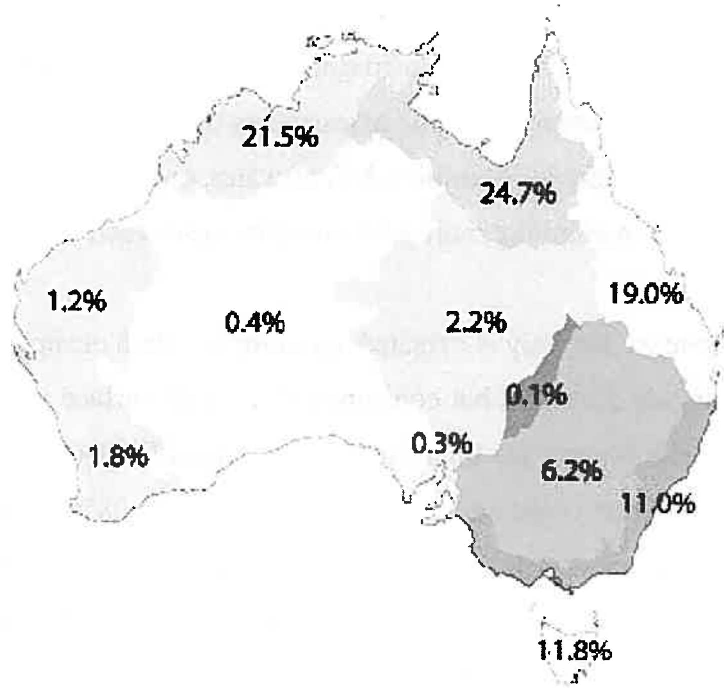

Figure 2.1: Percentage runoff distribution from each drainage division (source: NLWRA 2001).

Droughts and floods are common events in Australia. The continent is situated at the latitudes of the subtropical high pressure belt, which leads to generally drier climates. In addition, Australia is affected by the El Nino climatic events which cause weather fluctuations in the Pacific Ocean, at times inducing droughts in eastern and northern Australia (BOM 2007). One of the most severe El Nino events occurred in 1991-1995, and caused an estimated cost of $5 billion to the economy. Severe droughts could also be unrelated to the El Nino. Examples of this include the "Federation drought" from 1895 to 1903, during which stock numbers fell by more than 40%. Flooding is thought to follow droughts, due to the heavy rain accompanying the breakdown of El Nino. Flooding also occurs in the tropics during monsoon seasons, and commonly along the east coast and in the south induced by pressure systems. It is considered Australia's most costly natural disaster, inflicting $400 million a year in damages (BOM 2007).

Due to this climatic variability, a number of large storage dams have been constructed to secure water for human consumptive demand. Major irrigation expansion occurred in the

1950's and 1960's, with large irrigation projects funded by the federal government and operated by public agencies. The intention was to 'drought-proof' agriculture, which was based on the notion that the value of irrigated production and regional development justifies the cost of public investment in irrigation infrastructure. This notion however was not supported with rigorous economic assessments (Pigram 1986). To date, Australia has 447 dams with a capacity of 79 million ML of water, out of which around 20 million ML being consumed by agriculture, industrial and urban uses each year (NLWRA 2000).

The most water intensive industry is irrigated agriculture, which occupies less than 1% of total agricultural area in Australia but consumes 75% of all surface water diverted. This primarily occurs in the Murray Darling Basin (MDB) (DAFF 2006; CRCIF 2005). Most water is used for irrigation crops and pastures, making up 10,085GL or 90.5% of water used by agricultural establishments. The following table illustrates the agricultural water use by state in 2004-05, ranked by the level of consumption (Table 2-1). It can be seen that NSW ranks as the highest agricultural water consumer in Australia.

Table 2-1: Agricultural water use in Australia, by State 2004-05 (source: Trewin 2006).

	Agricultural establishments	Irrigation	Other agricultural uses	Total
	no.	ML	ML	ML
NSW(a)	40 162	3 716 557	259 551	3 976 108
Vic.	32 357	2 363 764	206 456	2 570 219
Qld	27 132	2 613 404	251 486	2 864 889
SA	14 111	877 818	^127 010	1 004 828
WA	11 915	267 098	162 274	429 372
Tas.	3 877	231 758	23 690	255 448
NT	380	14 198	31 440	45 638
Aust.	129 934	10 084 596	1 061 906	11 146 502

^ estimate has a relative standard error of 10% to less than 25% and should be used with caution

(a) Includes ACT.

Groundwater resources are also an important water source. Major groundwater basins underlie 60% of the continent, with the Great Artesian Basin extending over 22% of

Australia making it one of the largest aquifers in the world (AWRC 1975; DAFF 2006). The distribution of available groundwater resources are shown in Figure 2.2. There are confined and unconfined aquifers, in total providing a sustainable extractive yield of 25,780 GL (NLWRA 2001). Confined aquifers (artesian water) are overlain by an impermeable layer and held under pressure, such that water flows freely from the bore once it is tapped. Unconfined aquifers, on the other hand, do not have confining strata and requires pumping (AWRC 1975). Groundwater makes up 14% as a source of irrigation water for agriculture in Australia, however its use has grown dramatically in recent years as surface flows have become fully committed (Pigram 1986).

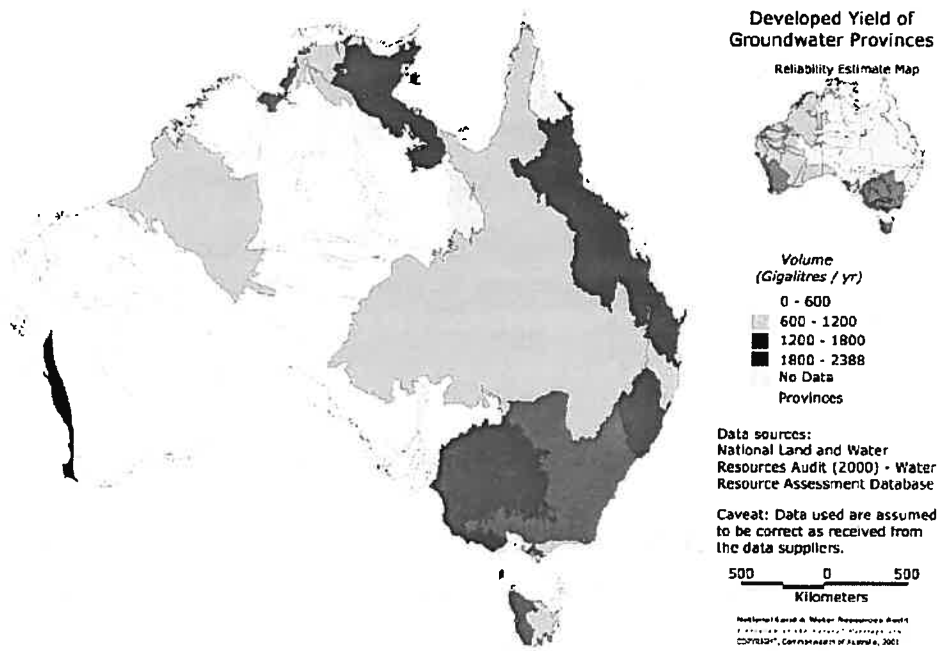

Figure 2.2: Sustainable yield of groundwater provinces (source: NLWRA 2001).

The MDB is the most developed agricultural area in Australia and covers 1million km^2, or 14% of Australia (AWRC 1975). It consists of two major tributaries; the River Murray begins in the Snowy Mountains of NSW which ends in South Australia, and the Darling River extends north through inland NSW which ends across the Queensland border (Figure 2.3).

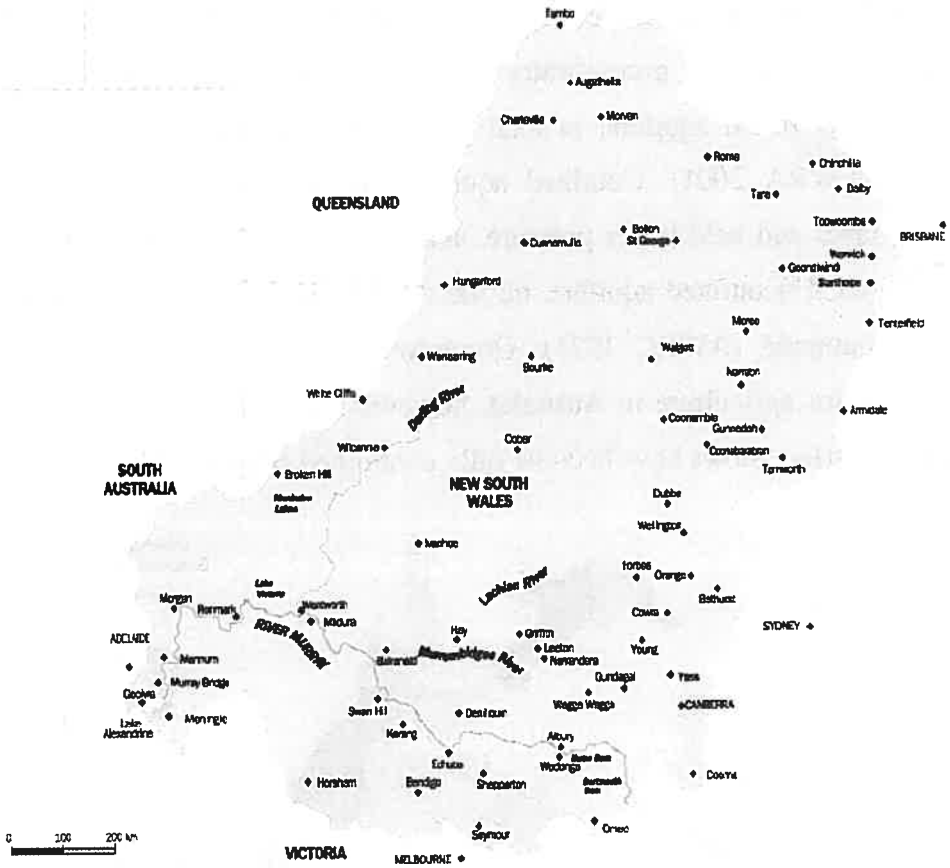

Figure 2.3: Murray-Darling Basin.

Prior to agricultural development, estimated average discharge from the mouth of the Murray was 12,900GL/yr, with flows ranging from 1,600 to 54,200GL/yr (CRCIF 2005). The bulk of in-river flows have been diverted with the expansion of irrigation schemes, with the volume of water diverted for agriculture over the last four decades increasing to over 12,000GL/yr (Figure 2.4). This severely affected flows at the mouth of the Murray, which now range from 0 to 27,464GL/yr (CRCIF 2005). While irrigated agriculture in the MDB contributes to more than 41% of Australia's agricultural profit, it has been argued that the resources would have been better spent on expanding dryland production or other agricultural enterprises, where there is comparative advantage (DAFF 2006; Davidson 1969).

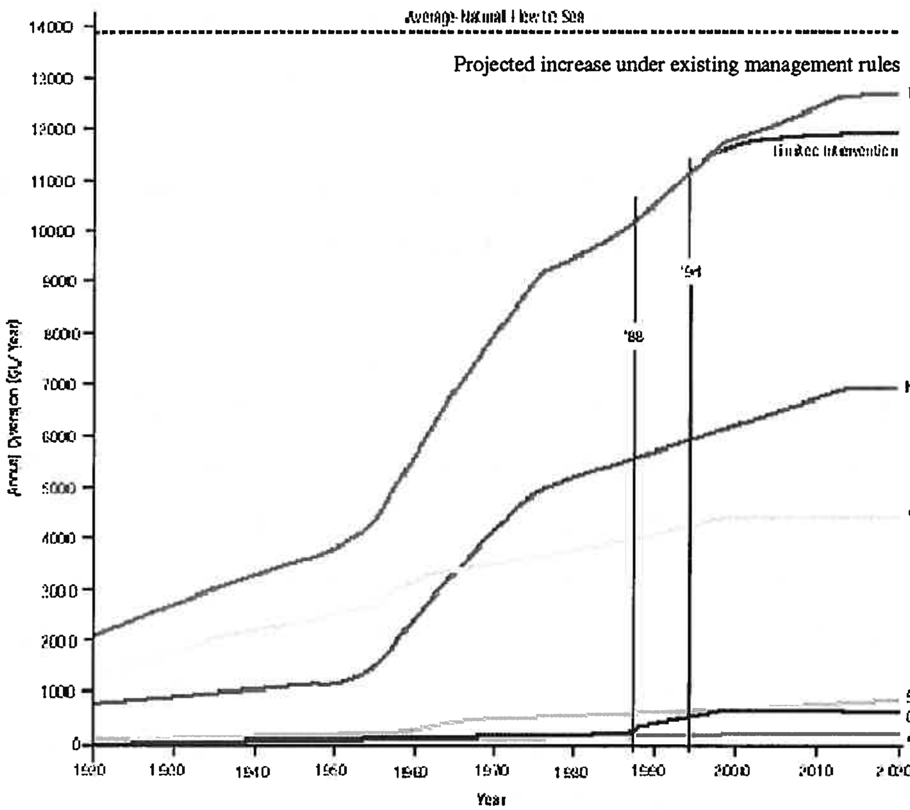

Figure 2.4: Growth in water use in MDB since 1920 (source: MDBC 1995).

2.2 WATER QUALITY AND SALINITY

Due to the variability of surface runoff and discharge, water quality is also extremely variable, especially given the high salinity of Australia's soil relative to other continents. Changes in water quality over time have been largely induced by landuse changes, which has been most pronounced after the introduction of European farming techniques. This includes the replacement of deep rooted vegetation with shallow rooted grasses and annual crops, which disrupts the natural water and salt balance, and the contamination of surface and groundwater from chemical and fertiliser use (MDBC 2001). The intensity of irrigated agriculture in the Murray-Darling Basin (MDB) is thus generally linked to the myriad of environmental problems present in the basin, including land degradation, river salinity, land salinity, water quality problems, and loss of biodiversity (MDBC 2001). The decline in river flow has seen a reduction of 60% of tidal areas which form the habitat for migratory birds, and an influx of exotic fish species, including European Carp, as a result of the decline in water and habitat quality (Oliver 2007; Wong et al. 2007).

The greatest economic consequence of environmental damages is dryland salinity, which is estimated to cost $247 million per year in the MDB (MDBC 2001).

Salinity is caused by natural salts in the soil being brought to the surface by rising underground water-tables. Australia's climate and historical geomorphic processes have led to a naturally high salt load in the soils, as a consequence of relatively saline surface waters (NLWRA 2001). There are two categories of salinity: primary salinity and secondary salinity. Primary salinity refers to the naturally occurring salts stored in the soil or groundwater that is slowly leached down below the root zone or is carried out of the system. Secondary salinity refers to the human-induced mobilisation of salts through land use changes, largely through irrigation and land clearing (Figure 2.5 and Figure 2.6). Dryland salinity is caused by the replacement of native deep-rooted vegetation, perennial trees, shrubs and grasses with annual crops and pastures that use less water, leading to a rise in the water-table. Irrigation induced salinity occurs through the application of irrigation water which percolates through the soil profile recharging groundwater, raising the water-table. Despite the marked differences between these two types, the hydrological process of both types of secondary salinity is fundamentally the same (DEH 2007).

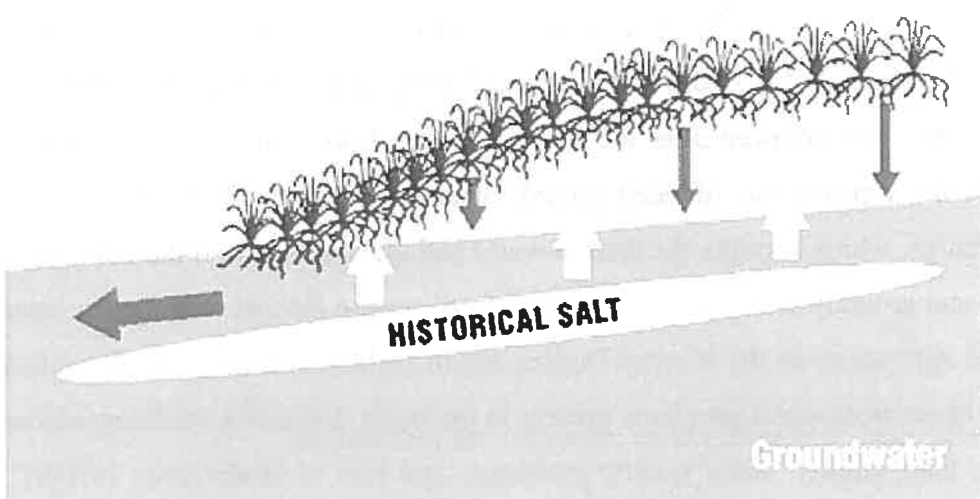

Figure 2.5: Dryland salinity caused by the replacement of deep-rooted natives with annual crops (source: NAPSWQ 2001).

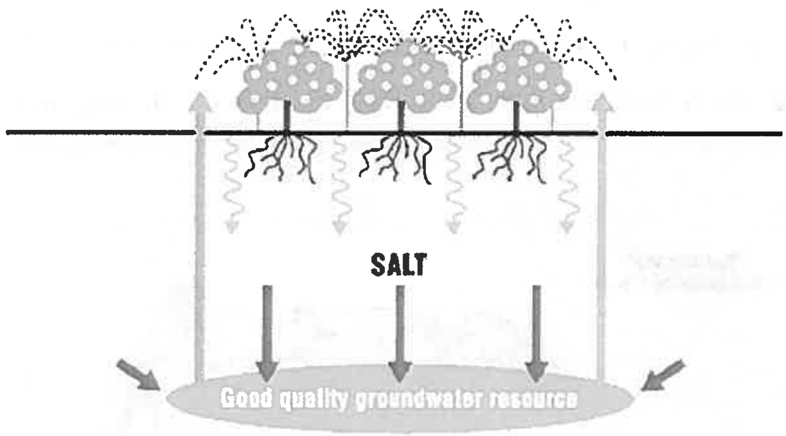

Figure 2.6: Irrigation salinity caused by excessive application of irrigation water (source: NAPSWQ 2001).

Salinity occurrence through time is closely linked to the hydrological functioning of groundwater systems, in particular the way it responds to changing recharge and how it is distributed. It is understood that increase in groundwater tables is a result of high rates of deep drainage (water loss below the root-zone) associated with current farming systems, contributing to groundwater recharge and secondary salinity (Asseng et al. 2003). However, there remains a significant information gap regarding the way the underground hydrological system reacts to altered recharge, due to the expense and non-transferability of studies. Often the response to landuse changes is very slow, taking between 10 to 10,000 years, and once the changes have taken place it takes a long time to achieve a new equilibrium (Jolly et al. 2001). Local flow systems, which have smaller capacity to store additional recharge, is thought to respond more rapidly to landuse changes, while regional flow systems have a large capacity and takes longer time to respond (DEH 2007).

The consequences of increased salinity include vegetation damage, dieback, water logging, saline waters and infrastructure damage. It is estimated that dryland salinity affects 5% of agricultural land, or 2.5 million hectares (NRM 2004). Salinity impact in the form of land and water degradation is thought to cost up to $3 billion per year, and a decline in bird varieties of 50%. Urban salinity damage in buildings and roads is also substantial. In the Namoi and Gwydir region in NSW, dryland salinity costs the households and businesses approximately $11 million per year, and a further $6 million to agricultural producers in terms of infrastructure and lost income (Wilson and Ivey 2001). In South Australia more than $6 million is spent on building maintenance alone (NRM 2004).

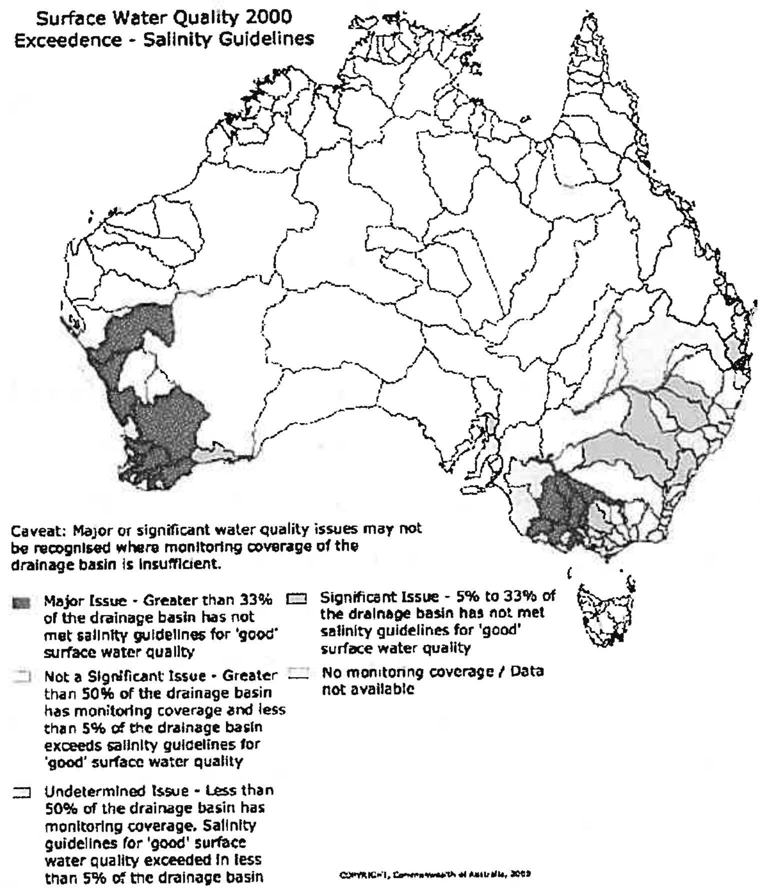

Figure 2.7: Surface water quality guidelines exceedance – salinity (source: NLWRA 2001).

The areas in Australia where salinity presents a problem are shown in Figure 2.8. The salinity afflicted areas are mostly in basins along the South-West Coast, South-East coast and southern MDB. However, some areas which show no signs of salinity problems may have insufficient monitoring coverage to indicate otherwise.

Salinity is measured through the electrical conductivity (EC) of the water. EC is related to the concentration of dissolved salt in the water, which allows electrical currents to flow through; the higher the salt concentration, the higher the EC reading. The level of EC in rivers also depends on the flow rates, where high flows dilute salt concentrations, giving a lower EC reading. However, the actual salt load that is exported can still be high in waters with a low EC, as salt loads are calculated as a multiple of EC measurement and the flow. Salinity can therefore be within stipulated standards while carrying significantly high amounts of salt loads downstream. Furthermore, projections of salinity risk based on historic river salinity can be of limited usefulness in predicting future salinity values due to the non-linear nature of salinity, as well as changes in climatic and production patterns (NLWRA 2001).

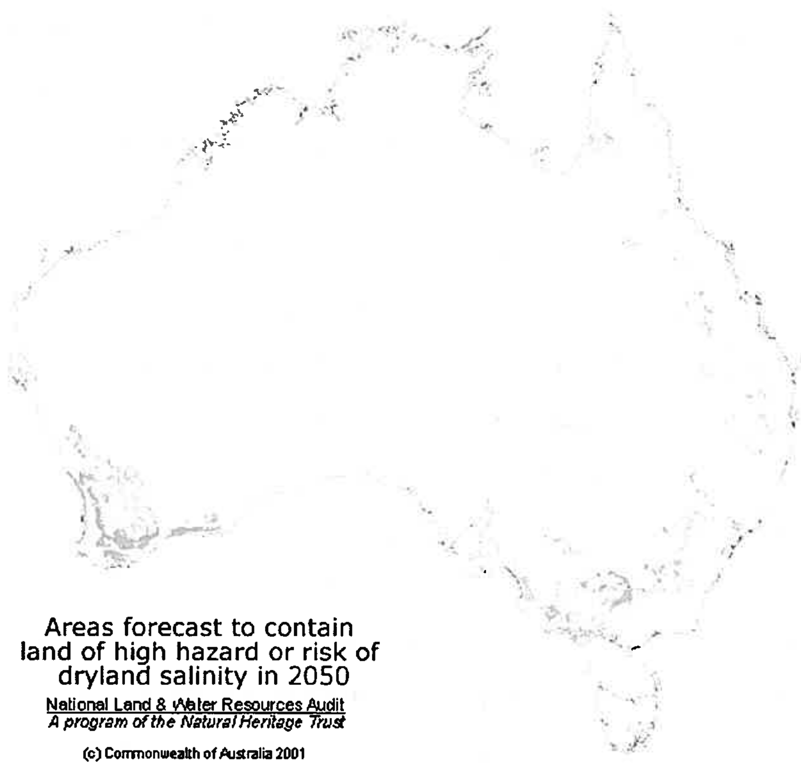

Figure 2.8: Forecast salinity risk areas in 2050 (source: NLWRA 2001).

Nevertheless, salinity risk maps are the best indicators available to determine areas where salinity will become a problem. It is predicted that almost all river basins in the MDB will have increased salinity in the next 50 to 100 years, and a number of national programs have been put in place to manage the salinity issue in Australia. These will be discussed at greater length in Chapter 3.

2.3 HISTORY OF WATER WORKS IN AUSTRALIA

The problem of water use can be attributed to the history of allocation and management of the resource. A first keystone development in Australian water management was the Irrigation Act 1886, formulated based on Alfred Deakin's report in 1884 (which investigated administrative arrangements of the irrigation industry in western America). This report subsequently formed the basis for Australian water laws and the push for the 'nationalisation' of water. This led to the overhaul of the 'prior appropriation' doctrine which gave water rights to individuals on a first-come-first-serve basis, and full ownership of water was handed over to the states. The objective was to productively utilise as much water on the largest possible area (Smith 1998), which reflects the sentiment that water left in the river has zero value. This also marked the beginning of heavy government involvement in water infrastructures in Australia.

By Federation in 1901, demand for irrigation grew with the development of agriculture, and more irrigation projects were commissioned with generous provisions made by the states and later by the Commonwealth. State governments vigorously encouraged the construction of large dams (Smith 1998). The imperative for development during this 'expansionary phase' of the water economy meant that economic considerations were sub-ordinate to the objective of rural expansion (Godden 1997). Large construction works were perceived as relief activity to generate employment, and it was during the period post World War II and the worldwide depression that several large dam projects have been commissioned. The first irrigation project in NSW was the Burrinjuck Dam that was completed in 1912, followed by the Hume Dam in 1936 (Smith 1998). The justification for these heavily subsidised projects was the long term returns generated from increased productivity and population growth (Davidson 1969).

The extent of government subsidisation essentially meant that the irrigation industry would not exist had irrigators been charged the full cost of dam constructions. These include the largest projects of its time, the Snowy River Scheme and the Ord River Dam, constructed between 1949 and 1974. These projects were subject to little or no economic assessments, and continued even where the economic and technical infeasibility had been known, due to ulterior motives including national prestige and political expedience. The cost of construction and operation had never been recouped, much like other schemes in this era, and irrigators only had to pay maintenance costs (Godden 1997).

The outcome of this 'developmental phase' was a substantial public debt on a number of these water infrastructures, which also deterred governments from financing further investments into its upkeep (Quiggin 2001). It was not until the 1970s that emphasis shifted to the management of water, as Australia's water economy shifted from its developmental to mature phase (Freebairn 2005). Furthermore, increasing environmental awareness meant that large-scale dam constructions are no longer favourable, with the damming of Lake Pedder in 1974 driving the green movement in Australia. The economic infeasibility of these dams was formally recognised with the 1992 Industry Commission report, that 'much of the past public investment in irrigation would not have proceeded had irrigators been required to meet full costs, including capital costs' (Industry Commission 1992 p. 85). The focus has since shifted towards the efficient management of currently developed water supplies to meet the ever growing demand, with the cost of dam operation being addressed through the cost-recovery process.

2.4 MATURE WATER ECONOMY

A mature water economy refers to the intensifying competition for water between users and uses, amid increasing social costs of securing more water supplies (Randall 1981a). For Australia, this comes as the cheapest and easiest sites for harnessing water resources were fully exploited during the national development phase, ending in the 1980s (Smith 1998). During the expansionary phase, the welfare cost of subsidies to water use was relatively small due to the lower social costs of expanded water use. However, as the water economy shifts into a mature phase, the management of water resources is complicated by policies inherited from the expansionary phase (Quiggin 2001). Most of the water resources in Australia have now become over-committed, with the paradigm now being the efficient reallocation of developed water supplies rather than the capturing of new water sources (Randall 1981a). The beginning of the mature phase can be regarded as the time the intergovernmental Murray-Darling Basin Agreement and the

Cap was introduced (Quiggin 2001). This involves the reallocation of water away from low-value uses to where it has higher value. The formation of water markets and pricing policies are crux to this reallocation, to facilitate the process of increasing water use efficiency.

Problems pertaining to water scarcity and allocation derive from early government policies to provide water to all users regardless of the cost, helped by the doctrine that 'water left in the river is wasted' as no value has been ascribed to its environmental significance. Cheap and heavily subsidised water had been supplied to urban and agricultural users through a string of dam constructions paid for largely by the public sector. This subsequently led to an overinvestment in irrigated cropping, accompanied by an underinvestment in water efficient technologies, and a gradual shift from dryland to irrigation farming including rice, cotton, and horticulture (Godden 1997; Arthington 1996).

The over-allocation of water entitlements has led to a situation of inefficiency, where the volume of water extractions far exceeds the level at which economic efficiency would be achieved. Such level would occur where the true opportunity cost of using water equates at the margin with the price of water. Where there are unpriced adverse or beneficial effects, the social cost diverge from resource and/or opportunity cost, which underpins the problem of water allocations because its price has not been cost-reflective. This is an artefact of initial water licence allocations which were originally area-based; such that licence holders were confined only by the area irrigated and the marginal cost to users was close to zero (Freebairn 2005). Hence, no explicit value had been tied to each unit of water; only a nominal licence cost and annual water fee which only captured a small percentage of operating and maintenance costs for distributing water from the main storages (Godden 1997). By the 1960s most licences were converted to volume-based licences to limit extractions due to escalating demands. However, the level of surface and groundwater extraction had persisted at unsustainable levels, leading to substantial environmental degradation in the river systems (PC 2003).

It was soon recognised that an allocation needs to be set aside for the environment as a legitimate user, and some reduction in the level of extractions is necessary. A significant turning point was the 1994 COAG statement, which proposed that the ownership of land and water be separated and that environmental needs for water be recognised (COAG 1994). The COAG agreements in effect reinforced the preference for price-based and market-based solutions to environmental problems (Quiggin 2001), which proposed for the capping of extraction levels; clawing back entitlements through government buy-back; and through cost-recovery, by incorporating the true opportunity costs into water charges. Extensions to the reforms in 2002 and 2004 highlighted the need for secure water rights to encourage water trade and a cost-sharing framework for reductions in entitlement (Freebairn 2005). Some irrigator groups in cotton regions have foreshadowed such problems arising from over-allocation of irrigation entitlements as early as the 1970s, and called for more sustainable development of water resources. In the Namoi Valley, this led to a voluntary embargo by cotton irrigators on issuing further groundwater licences in 1983 (Hamparsum, 2004). This was in contrast to the proposal by the NSW Water Resources Commission in 1983, to "mine the [groundwater] resource over 30 years, not allowing for recharge" in the Namoi Valley (Commonwealth of Australia 2003, p.p. 15014). It was also claimed that irrigators were told by authorities to activate their irrigation licences or they would be lost in conversion to volumetric licences because it was done according to history of use (Anthony, 2003), although there has been no official record of such advice (Jobling, 2000). Nevertheless, it appears the opportunity to acquire low-value entitlements at relatively low cost, has been lost.

2.5 THE CAP AND THE WATER MARKET

The low price paid for water means that there has been a lack of incentive to utilise water in a manner that corresponds to its true opportunity cost. This has led to an over-extraction of water and underinvestment in water efficient technologies (Zilberman et al. 1991). To remedy the situation of excessive wateruse, the Cap was introduced in 1995, following the completion of a water audit of diversions from rivers within the MDB. This audit had shown water diversions averaging at 10,800GL/yr and increased by 8% over the preceding six years. The Cap varies from state to state. For NSW and Victoria, the

Cap is the "volume of water that would have been diverted under 1993/94 levels of development" (MDBC 2003 p. 4). This volume also varies within the state, depending on the catchment in question. However, NSW has been lagging in the process of defining the Cap for some valleys, specifically the Border Rivers in northern NSW (MDBC 2007b). South Australia has been the most progressive with implementation of its Cap, having not issued any new allocations since the early 1960s. It was also the first state to sever water property rights from land in 1997 and allowed for licences to be temporarily traded (MDBC 2003).

The purpose of imposing a Cap on the level of diversions for consumptive uses was to limit the over-extraction of water and provide water for environmental services (MDBC 2003). The capping effectively increased surface water scarcity, resulting in an increase in demand for irrigation water and the need for an effective water market to be developed (Heaney et al. 2002). The market that is established has enabled trade to occur and an explicit price to be placed on water. Irrigators have the option to purchase water where allocations are insufficient to meet crop requirements; alternatively they can receive revenue from the sale of water allocations. This should reveal the true value of water, such that its opportunity cost is reflected in the market prices and encourages efficient use, (Randall 1981a). A properly functioning water market is thus a conduit to efficient allocation of scarce water resources, because it allows water to be diverted from lower value uses to higher value uses.

However, the price of water remains difficult to estimate due to administrative impediments and the existence of a relatively 'thin' market, whereby there are few participants in the market to create competitive conditions of trade. Trade in permanent water entitlements has been less than 1% of diversions in 2001-02, with less than 1% of all trade occurring inter-regionally (Heaney et al. 2004). There has been a general apprehension towards the water market, drawing from concerns pertaining to community decline, threat of foreign ownership, and a perceived loss of subsidies (Randall 1981a). Crase and Jackson (1998) (in Crase et al. 2000) reported that only 2% of farmers in the Murray region would consider permanently selling their water entitlements. Gaffney

(1997) also reports the lack of motivation for sellers to participate in trade as a significant hindrance, with the only participating irrigators being those intending to exit the industry or facing financial debt. The perception that demand will grow perpetually is another reason irrigators withhold from trade. This appears to be the sentiment of many irrigators in the Namoi, with the expectation that if the entitlement is sold then they will need to buy it back in future at higher prices. The preference is therefore to invest in water efficient technologies rather than buying more water to augment supply (Morgan 2005, pers. comm.). Skepticism is also expressed, based on 'philosophical' grounds that water should not be traded like a commodity (Norrie 2006, pers. comm.). This view reflects the lack of understanding and acceptance of water trading, even on a temporary basis.

Complexities including the interconnectivity between surface and groundwater, and the trade of water into salinity-prone regions exacerbating environmental problems, have further prevented the full benefit from trade to be realised (Young and McColl 2005). This led to the conjecture that the costs involved with creating perfectly defined water access right to be greater than the potential benefits that would be derived from trade (Beare et al. 2001). Bennett (2005b) also cautions against the promotion of one institutional arrangement over another, e.g. market-based approach over 'command and control', without consideration for the transaction costs involved and its distribution amongst affected parties. The benefit that market instruments could provide should be assessed on a case-specific basis to determine its virtue.

2.6 COST RECOVERY

The pricing mechanism has an important role in achieving efficient resource use, by providing coordinating market signals for its distribution (Randall 1981b). However, the price of water charged to irrigation licence holders has for a long time reflected a relatively small portion of the state's costs of running the irrigation infrastructure and had little account to the future availability of the resource. Government policies in the past have perceived water security as a priority, and many schemes were put in place to ensure water is delivered to meet demand. Regional development was emphasised as a justification for irrigation schemes that were economically unjustifiable (Davison 1969).

In turn, the provision of water has imposed significant costs on the authorities managing the infrastructure, since the price of water never reflected the true cost of supply. There was also public concern over the impacts underpricing is having on the environment, since environmental costs have generally been overlooked in decisions to allocate water for irrigation (Godden 1997). The economic rationale to water pricing for public irrigation schemes in Australia has been to recover only annual operating costs, which are relatively low (Godden 1997). Current cost-recovery processes, whereby higher water charges are being implemented for regulated river systems, aim to correct the over-exploitation of river systems and the inefficient use of scarce water resources. By increasing the private costs of using water for production, the external cost of over-extraction is minimised if prices charged reflect more closely to the true social cost of water extraction (IPART 2004). It is also important for further investment to rebuild run down infrastructure, which the government has been reluctant to do because of its history of unsuccessful investments in water infrastructure (Smith 2000).

Cost-recovery plans for water services have been recently implemented in NSW to address these concerns. In the cost-recovery process, the level of licence fees and water charges to all users are revised upwards each year to recoup current costs incurred by regulators (DLWC 2001). This is in accordance with the COAG 1994 Water Reform Framework to stem natural resource degradation caused by the under-pricing of bulk water services (COAG 1994). A medium term price path was proposed in a submission by the Department of Land and Water Conservation (now Department of Natural Resources), whereby the fixed charge and usage charge for irrigation water was set to rise by 20% each year from July 2001 to June 2004 (DLWC 2001). It was envisaged to allow an 86% level of cost recovery of the expense of running water services, compared to 54% under earlier pricing arrangements. Some valleys only required only small increases in regulated water charges to achieve full cost recovery, while other valleys require very large increases in both regulated and unregulated water charges (IPART 2001).

The pricing structure as set out by the NSW Independent Pricing and Regulatory Tribunal (IPART) is such that bulk water prices are in the form of a two-part tariff (Table 2-2).

This major change was made in 1997/1998, with a fixed charge on licence entitlement and a variable charge on water use. The two-part structure is intended to provide financial viability for the operation of dams and also to provide a conservation signal to users (IPART 2004). However, this price structure had only applied for regulated rivers, not unregulated systems (rivers without an up-stream head dam to control downstream releases of water), where irrigators were still charged on a per-hectare basis. In unregulated systems, a two-part tariff does not apply until area-based licences have been converted to volumetric licences (DIPNR 2004a). This had not occurred for many unregulated systems until Water Sharing Plans were gazetted in 2004, with the original pricing system in place until proper metering and monitoring is implemented to allow accurate determination of water extraction (DIPNR 2004a; Hudson 2005, pers. comm.).

Table 2-2: Cost recovery level for river systems in NSW (source: IPART 2001 p. 40).

	Regulated Water	Unregulated Water	Ground Water
Border	83%	26%	Barwon region
Gwydir	87%	53%	
Namoi	81%	28%	22%
Peel	44%	Included in Namoi	
Lachlan	83%	17%	Central West
Macquarie	116%	43%	21%
Far West	No regulated rivers	20%	21%
Murray	82%	20%	34%
Murrumbidgee	91%	43%	17%
North Coast	7%	13%	16%
Hunter	36%	19%	15%
South Coast	24%	13%	6%
Total	81%	19%	20%

2.7 WATER ENTITLEMENTS AND SEASONAL ALLOCATIONS IN NSW

The water entitlement in NSW can be grouped according to its supply reliabilities. The highest priority is given to local and major urban water utilities, followed by high security entitlement holders, with general security licence holders allocated a share component only after other higher priority users' requirements, or 'fixed commitments', have been met first. These include environmental provisions and high security supply commitments. High security licence holders are guaranteed to receive full allocation in all but the worst drought years, and two years worth of water supply is reserved in dams to meet the demands of high security users. Each licence type is subject to a different set of prices, reflecting the degree of water security. The assurance of water supply is reflected in higher fixed and variable usage charges for high security licence holders than general security users (PC 2003).

Around 90% of NSW entitlements are general security, while perennial crops are mostly under high security licences (PC 2004). The volume of water available for extraction is announced at the start of each season by the water authority, known as the Available Water Determination (AWD), which is then apportioned to licence holders within the water district. AWD announcements can be made throughout the year for general security licences if more water becomes available (DIPNR 2004c). All NSW water access licences are kept in NSW Department of Lands Water Access Licence (WAL) Register, and Department of Natural Resources (formerly DIPNR) forwards any changes to access licences, such as annual AWD credits, to the Department of Lands for updating (DIPNR 2004c). The seasonal allocation given to each licence holder is a percentage of the Share Component specified in the entitlement (Figure 2.9).

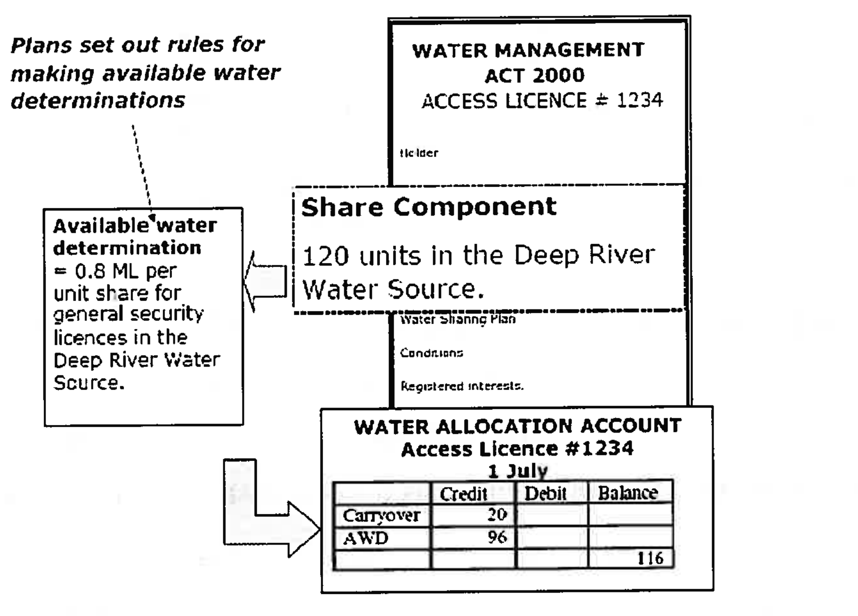

Figure 2.9: Allocation of a season's water to licence holders' accounts (source: DIPNR 2004c).

The AWD credits can be accumulated and used across seasons, as part of the carry-over rules. These rules have been introduced so that irrigators can carry-over part of the unused seasonal allocation into the following year, providing an incentive to be water efficient. The maximum volume that can be carried over from one water-year to the next is 100% of the share component, with an allowable 200% extraction in any one year and a maximum of 300% accessed over three rolling years (DIPNR 2004b). That is, in any one year the maximum extraction permitted is the two-year water allocation, whereas the extraction limit cannot exceed allocations received over a rolling-three years. Irrigators could then choose to bank some water for the following season or use more in the current production. The objective of introducing carry over rules was to provide greater flexibility and an incentive for conservation, rather than to exhaust all allocations within one year.

2.8 SUMMARY OF CHAPTER 2

The evolution of Australia's water economy was presented in this chapter, which was shown to be linked to geographical variability in water resources in Australia. The environmental problems that have arisen from the over-extraction of water resources, particularly salinity, were discussed. This has led to a number of government initiatives which aimed at creating a sustainable level of resource use and were discussed in brief. The next chapter will discuss the trend in water management in Australia in detail, and how it has been implemented through the various institutional arrangements.

Chapter 3.

INSTITUTIONAL ASPECTS

In this chapter, an appraisal of the various intergovernmental arrangements in Australia's water economy is conducted. The objective is to provide an understanding of how water management principles have been implemented in practice, and the range of catchment policies that affect irrigators in Australia and in NSW.

3.1 RIVER MURRAY WATERS AGREEMENT AND THE MURRAY-DARLING BASIN AGREEMENT

The earliest intergovernmental agreement in Australia was the River Murray Waters Agreement (RMWA) in 1915. The agreement was made between the Commonwealth, New South Wales, South Australia and Victoria, and marks the beginning of intergovernmental cooperation over water resources. The issues were initially related to securing a share of water supplies, with the stimulus being the severe drought from 1895 to 1902 which had prompted the colonies and States to forge an agreement to manage the Murray River. This Agreement was especially significant for South Australia, because it guaranteed the State a minimum flow. Various amendments to the RWMA were made over the 70 years of its operation, although these were only minor changes relating to the construction of dams and weirs (MDBC 2006a).

Over time, environmental damage in the basin became more noticeable. However, it was not until 1984 that a more concerted effort was made to addresses the resource and environmental problems that were increasingly prevalent in the basin. It was eventually recognised that problems with rising water and land salinisation, amongst other natural resource issues in the basin, extended across borders and collaboration between the jurisdictions was required to sufficiently manage these problems. The outcome was the Murray-Darling Basin Agreement, signed by the governments of NSW, Victoria, and South Australia in 1992 and legally enforceable under the Murray-Darling Basin Act 1993. By 1998, Queensland and the ACT both became signatories to the agreement. The

Agreement also saw the creation of the Murray-Darling Basin Commission and the Community Advisory Committee (CAC), responsible for the coordination of planning and development of policy pertaining to the sustainable and equitable use of the Basin's resources (MDBC 2005b). The transition of the water economy from the developmental phase to the mature phase is reflected by the change in focus in water management doctrine during this period. The objective was no longer to use as much water as possible, but to achieve sustainable use between human use and environmental protection through a coordinated approach. The MDB Agreement is enforceable by legislation, and was signed in the same year when the Council of Australian Governments (COAG) was formed in 1992 (COAG 2005a). The formation of the COAG led to a succession of water reforms in Australia, with the environment playing an increasingly significant role at each stage.

3.2 COUNCIL OF AUSTRALIAN GOVERNMENTS AND THE MURRAY-DARLING BASIN COMMISSION MINISTERIAL COUNCIL

The Council of Australian Governments (COAG) comprises the Prime Minister, State Premiers, Territory Chief Ministers and the President of the Australian Local Government Association. Its primary function is the development and execution of policy reforms, significantly the implementation of the National Competition Policy (NCP) and water reform. Commonwealth-State Ministerial Councils are formed under COAG as facilitating bodies for joint action between Contracting Governments to develop, coordinate, and monitor policy reform under consideration by the Council. Over 40 Ministerial Councils have been established under COAG, including the Murray-Darling River Ministerial Council which was created as part of the Murray-Darling Basin Agreement (COAG 2005b). These bodies are responsible for the implementation of the Murray-Darling Basin Initiative (MDBC 2001). The Commission is the executive arm of the Ministerial Council, and is an autonomous body separate from government organizations or departments.

The Commission develops and implements policies by working cooperatively with the partner governments, committees, and community groups, with the aim to devise integrated management of the Murray-Darling Basin. The Community Advisory Council (CAC), also created under the Agreement, comprise of people with varying areas of expertise and with networks throughout the Basin. Its role is to provide the Council with advice from a community viewpoint on natural resource management issues, and to enhance the adoption of management strategies. The CAC has had an active role in the establishment of salinity management programs, integrated catchment management, the establishment of the Cap on diversions, and environmental flows (MDBC 2001).

The Murray-Darling Basin Agreement, enforceable by the Murray-Darling Basin Act, contains a section specifying the requirement for States to implement a Cap on diversions. Each Contracting Government is bound by the Murray-Darling Basin Agreement to comply with annual diversion targets set out by the Ministerial Council (MDBC 2004). To hasten the progress of the Agreement, the implementation of the Cap, as a part of greater water reform, has been tied in with the NCP which provide financial incentives to motivate its implementation. The NCP payments were the first of a string of Federal funding aimed at promoting full water reform in the years to come.

3.3 COUNCIL OF AUSTRALIAN GOVERNMENTS WATER REFORM AND THE NATIONAL COMPETITION POLICY

The water reform process has been underway since early 1990s, as part of a wider micro-economic reform agenda towards liberalised national competition. It was recognised during this phase that water extraction for consumptive uses in the Murray-Darling Basin is exceeding sustainable levels. Water reform subsequently became a key issue in the 1994 Council of Australian Governments (COAG) meeting during which the Contracting Governments agreed to a Water Reform Framework for water resources, to implement a "strategic framework to achieve an efficient and sustainable water industry" (COAG 1994). This agreement was based on the Working Group on Water Resources Policy commissioned in 1993 which concluded that the water industry had significant inefficiencies and was unsustainable. The Working Group's recommendations for the reform process significantly advocated the separation of water property rights from land title, allocation of water to the environment as a legitimate user, putting in place necessary institutional arrangements to facilitate water trade, and the need for full-cost recovery of water delivery costs and assets (Smith 2000). The key accomplishment from the Water Reform Framework has been the incorporation of environmental considerations in water use decisions. Water management plans have been developed by governments to provide for ecological flows, and an embargo placed on new water allocations from stressed water bodies.

The process of water reform is stimulated by the endorsement of the National Competition Policy (NCP) by COAG in 1995. NCP payments were tied into the framework to accelerate the rate of water industry reform and to facilitate structural adjustment in the process, not just for water but for structural reforms in other industries. This agreement evolved from the governments' microeconomic reform imperative over the past decade which aimed to reduce barriers to free trade in all areas of the economy. The reform agendas were based on the 1992 Hilmer inquiry into a National Competition Policy for Australia, which provided recommendations for the direction of reform. Significantly, the report advised the implementation of competitive neutrality principles to reduce the competitive advantage inherent to publicly owned enterprises and to revise legislation inhibiting competition in key industries. With respect to water, the reform was to allow for more sustainable water use through efficient pricing, which reflects the true cost of water delivery and thereby improves conservation signals to users (NCC 1998).

An Implementation Agreement was drawn up under the NCP, where the Commonwealth Government made available NCP payments to each State and Territory on condition that satisfactory progress was made in the direction of recommended reforms agreed to in the NCP. Each government reports annually to the National Competition Council (NCC) on progress made with implementing the agreed reforms. An assessment of each State and Territory's progress is made by the NCC prior to 1 July of the years 1997, 1999, and 2000 to determine whether the jurisdictions had met conditions upon which payments were to be made (NCC 1998).

However, despite the NCP payments, progress since have varied between the states. While the intergovernmental Murray-Darling Basin Agreement and 1994 COAG Agreement has set the foundation for a basin-wide perspective on water management, disputes remain between upstream and downstream states. There has been regular blame-shifting and under-resourcing by contracting governments, which has hindered the implementation of full water reform (Howard 2007). Additional funding from the Federal government have since been made out to the States, and further agreements to address the impediments to full water reform have been initiated. This includes the National Water Initiative in 2004, essentially an enhancement of its predecessor the 1994 COAG Agreement, and was a keystone event in the water reform history.

3.4 NATIONAL WATER INITIATIVE

At the 2002 COAG meetings, it was agreed that an update of the 1994 Water Reform Framework was needed to overcome obstacles in the reform process, in particular for clearly defined property rights in order to mediate the uncertainty for water users (Freebairn 2005). The crux of the problem was the determination of environmental flow requirements and allocations, stemming from the lack of clearly specified water property rights between extractive users and ecological services. A report from the Chief Executive Officers' Group on Water was presented in the December 2002 COAG meeting, suggesting national principles on water allocation and entitlements. The principles outlined in the report, and after extensive consultation with key stakeholders, subsequently provided the basis for the National Water Initiative (NWI) (NSW Farmers' Association 2003). The purpose of the NWI was to establish a nationally compatible system of water access entitlements, efficient water markets, institutional arrangement for the recovery and management of water for the environment, improved accounting and best practice water pricing, and urban water issues. The key objectives of the NWI include:

- The encouragement of permanent trading and more cost-effective water recovery to achieve environmental outcomes;

- To improve public access to information, more compatible registry arrangements, monitoring, reporting and accounting of water use.;
- More comprehensive and transparent water planning;
- To address over-allocated systems as quickly as possible (COAG 2004).

The NWI was endorsed at the June 2004 COAG meeting, and is regarded as a landmark agreement in which all stakeholders agreed to a framework to meet the objectives of both consumptive and environmental use (Borthwick 2006). The Natural Resource Management Ministerial Council oversees the implementation of NWI objectives by each State and Territory, although the assessment of progress made with NWI is undertaken by the National Water Commission (NWC), created at the June 2004 meeting with the endorsement of the NWI. The 2005 assessment of compliance with water reform commitments under the National Competition Policy were also carried out by the NWC (COAG 2004).

Another key responsibility of the NWC is the allocation of the Australian Water Fund (AWF) set up by the Prime Minister in December 2004, for which further funding was made available by the Federal government. A commitment of $2 billion over five years was to be allocated amongst three programs under the umbrella of AWF: Water Smart Australia, Raising National Water Standards, and Australian Water Fund Communities. Funds allocated to activities under the Water Smart Australia programme are for encouraging the adoption of 'smart technologies' and better management of water use at the farm level. The Raising National Water Standards Program invests funds to increase the ability to monitor and measure water use, and the Community Water Grants program provides grants to communities to promote efficient water use. These programs are jointly administered by the Department of the Environment and Water Resources (formerly Department of Environmental and Heritage), and the Agriculture, Fisheries and Forestry departments (DPMC 2006). Further to the NWI agreement was the development of the Living Murray Initiative, to target and prioritise the ecological assets in the MDB that are to be protected. The contracting governments to COAG have pledged significant funding towards achieving these targets, although it appears that progress has been lagging.

A common theme that has emerged throughout the course of these agreements is the lack of clear, measurable objectives associated with the funding that have been injected at different stages of the water reform process. This is a trend that is also observed in other intergovernmental strategies carried out by the Murray-Darling Basin Commission.

3.5 MURRAY-DARLING BASIN COMMISSION: LIVING MURRAY INITIATIVE AND FIRST STEP AGREEMENT

The Murray-Darling Basin Commission (MDBC) created The Living Murray program in mid 2002 in response to the degradation of the River Murray system. Part of the initiative was the First Step program, developed in 2003 and identifies six significant forests and lakes in the Murray Darling Basin – the six significant ecological assets – to be protected in the five years following the creation of The Living Murray initiative (MDBC 2005b). The implementation of The Living Murray First Step is enforceable through the Murray-Darling Basin Water Agreement, endorsed as part of the National Water Initiative (NWI) signed at the June 2004 COAG meeting. The contracting governments agreed to commit $500 million over five years, commencing 2004-2005, for the implementation of actions specified in the Living Murray First Step, including the recovery of (on average) 500GL of water per year (DPMC 2006). This volume is thought to provide one-third of the water the river needs (Sexton 2006). Complementary to this funding, a total of $150 million has also been set aside by the MDBC in 2002 to be spent over eight-years (2003-2011) on the Environmental Works and Measures Program, targeting six significant environmental assets in the Murray-Darling Basin (MDBC 2005b). Although the funding is substantial, the figures appear to be chosen out of expediency rather than well justified on economic grounds. It was soon apparent that the initiatives lack clearly defined deliverables to rationalise the sums allocated, and inevitably led to more criticism regarding the governments' slow progress.

The Commonwealth's perceived solution was to make a one-off payment of $500 million to the MDBC to hasten the process. This sum would be spent over five years from 2006 to accelerate the implementation of Living Murray Initiatives agreed by the MDBC in 2003 (COAG 2006). Almost $250 million of the lump sum payment will be used for capital works and improvements in infrastructure, including upgrading weirs, enclosing canals, and building fish ways. A further expenditure is to increase flows directly by purchasing entitlements off irrigators who have achieved water savings (Sexton 2006). Altogether, the agreements amount to a significant sum, however it remains short of defined, measurable outcomes associated with each initiative.

Little has been achieved since the Living Murray program commenced in 2003, and only a few water-saving projects have been undertaken (Sexton 2006). The funding committed to the NWI and Living Murray Initiative has exceeded $1 billion since 2004 without corresponding accomplishments that reflect this expenditure. Projects under the Living Murray are mostly still under development or investigation, and the recovery of an average 500GL per year is not expected to be realised till 2009. The projects that have been implemented to date altogether provide just 270GL, through 'market-based' solutions, buying back water entitlements from irrigators, or infrastructure projects such as improved piping (MDBC 2007a). The implementation of the Cap has also been delayed in three of the contracting states, some of which are not expected to be finalised till 2008 (MDBC 2007b). Furthermore, it remains uncertain what the economic implications of the water reallocation targets are for irrigators, and whether the revenue allocated towards this end are justified or insufficient.

3.6 NATIONAL PLAN FOR WATER SECURITY

In January 2007, the Federal Government announced yet another initiative to 'fix' the water problem of the nation. The strategies outlined in the National Water Plan were in accordance with the objectives outlined in the NWI, specifically to address over-allocation, modernise irrigation, to improve water information availability and to create a transparent water management regime. This involves an allocation of $10 billion over 10 years, with the majority of the expenditure dedicated to advancing work carried out under the Living Murray Initiative and the Australian Water Fund. The breakdown of the funding is as follows:

- $6 billion for improving water use efficiency on-farm and off-farm, with $1.5 billion allocated towards subsidising the cost of water efficient technologies and the rest used to improving delivery system efficiency and monitoring;
- $3 billion for structural adjustment, to retire unviable or inefficient irrigation areas and to buy-back water entitlements;
- $600 million to reconfigure the governance of the MDB, by transferring all jurisdictional power over the system from the State Governments to a single minister under the Commonwealth Government;
- $480 million dedicated to improving the accuracy and availability of water data. This involves the creation of comprehensive, transparent water accounts and metering on a national scale. These functions will be carried out by the Bureau of Meteorology.

This is a substantial amount of funding that has both positive and arguably counterproductive features. A small, but important, element of the plan is the gathering of water information. It requires that irrigators "share all of their existing water data assets with the Bureau [of Meteorology] and transfer all new data to the Bureau as it is collected" (Howard 2007, p. 17). Under current arrangements, even where water metering is in place, water extraction data is considered confidential information and is not publicly disclosed (Hudson, pers. comm. 2005). The new arrangement would require irrigators to disclose such information to a government department, allowing for better water management through accurate monitoring of water use on a national basis. This is envisaged to significantly improve the ability to manage Australia's water resources.

On the other hand, provisions in the Plan to improve on-farm water use efficiency, in the form of a subsidy for modern irrigation technologies, may conflict with the objective to retire inefficient irrigation areas. The financial assistance for water efficient technologies would allow less efficient irrigators to remain in the industry, and to use the water savings to expand irrigated production (Ancev and Vervoort 2007). In this sense, the value of such properties become inflated and unnecessarily increases the cost of structural adjustment or the buy-back of water entitlements.

It can be seen that sustainable water use and environmental protection has gradually become the focus of discussion throughout the course of water reforms over the last two decades. While generous amounts of government funding has been put towards achieving 'sustainability' during this period, the 'efficient' allocation of water between extractive and ecological uses has remained a point of contention. In particular there is significant uncertainty regarding the value ascribed to the environment that is required to justify the cost of water reallocation.

3.7 BASIN SALINITY MANAGEMENT STRATEGY

Other existing intergovernmental agreements surround the management of water quality, significantly salinity. One such agreement is the Basin Salinity Management Strategy (BSMS), an initiative by the Murray-Darling Basin Ministerial Council that began in 2001. The salinity management framework set out in the BSMS is associated with the National Action Plan for Salinity and Water Quality, endorsed by the COAG in 2000. The National Action Plan identified nine priority regions in the Basin that are at risk of salinity, and are targeted by strategies set out in the BSMS. One key feature is the end-of-valley salinity targets for each tributary catchment and a Basin target at Morgan in South Australia. The objective is to maintain the salinity at Morgan at less than 800[1] EC units for 95% of the time, with the overarching aim to halt environmental degradation and for safe human use (MDBC 2006b). The end-of-valley targets set for catchments in the MDB were determined based on this objective. Essentially, the salinity level will be capped to limit the salt load entering the basin, in particular to protect the assets at risk of salinity that have been identified in the National Action Plan. The projects to achieve end-of-valley targets in each tributary include a mix of land management, engineering and river flow options, the choice of which depend on the State and catchment community priorities.

[1] 800 EC units is the recommended safety limit for human consumption.

For the Namoi River Basin, where the case study area of the Mooki catchment is situated, the mean salt load target is 127,600t/yr and a mean salinity level of 440µS/cm (MDBC 2005a). This makes Namoi the third highest contributor to the salt load received in the MDB, carried down-stream into the Barwon-Darling system which flows into the Darling River. In fact, the three largest contributors of salt load to the MDB are all located in NSW (Lachlan, Murrumbidgee and Namoi valleys). There is a strong justification to manage the salt load and salinity levels in these catchments in NSW.

3.8 WATER ACTS IN NSW

State legislation relating to water management varies between states. In NSW, water resources are regulated by the Water Management Act (WMA) 2000, which replaced its predecessors Water Act 1912 and the Water Administration Act 1986. The intention of water law was originally for administrative and legal arrangements over the use of water, which is subject to steadily increasing competing demands (Smith 2000). Licences were originally area based, however in 1981 licences were redefined to limit the volume that licence holders could access due to escalating demands, with volumetric limits implemented first in the River Murray and soon after in other systems (PC 2003). However, the level of surface and groundwater extraction continued to escalate to unsustainable levels in much of NSW, and led to substantial environmental degradation in the river systems. Following the 1994 COAG agreement, significant water reform took place in NSW including setting sustainable access limits as part of the WMA. This subsequently led to the current definition and access rules for water licences in NSW (Smith 2000).

The WMA stipulated the creation of a registry for the administration of water licences, which detail the share and extraction components, and the expiry date of ownership (see Section 2.7). The registry is managed by the NSW Department of Lands for the Department of Natural Resources (DNR) and is responsible for licence administration, renewals and transfers (temporary and permanent) (PC 2003). These access licences are linked to the Water Sharing Plans (WSP) developed by representatives of DNR (DIPNR 2004b).

The rules under the WSP are as follows. WSPs are a requirement of the WMA, and were created for the sustainable use and sharing of water resources in both regulated and unregulated river systems. The most significant aspect of the WSP is the criterion for a share of water to be allocated for the environment, comprising of environmental health water, supplementary environmental water, and adaptive environmental water (ACIL Consulting 2002). 'Environmental health water' is the volume of water committed to fundamental ecosystem health and may not be diverted for other purposes. Supplementary environmental water is committed for specific ecological services at specific times and circumstances, and may be taken for other purposes at other times. Adaptive environmental water is intended for specific environmental purposes of private entitlement holders (PC 2003). The rules for water sharing are established as commence-to-pump (CTP) rules, which specify the minimum in-stream flow the river must reach before irrigators could commence pumping (Aluwihare et al. 2005). The minimum flow accounts for the environmental health water, for this thesis is referred to as environmental flows. DNR is the body responsible for the assessment and implementation of the WSPs. Many water districts have been converted from the Water Act 1912 to the new Water Management Act 2000, which occurs once the WSP for the valley has been gazetted and commenced (DIPNR 2004a). However, up until 2004, plans for many river systems were still being formulated and assessed (Hudson 2005, pers. comm.), so valleys under area-based licences were still charged flat rates. Once the WSP is implemented, all irrigation licences are converted to volume-based licences and subject to a two-part tariff, in line with cost-recovery principles. There is also a differentiation between the cost of supply to a regulated system (rivers with an upstream head dam to control flows) and an unregulated system (rivers without an upstream head dam). In NSW, the prices set to recover the cost of dam operations and water services are set by the Independent Pricing and Regulatory Tribunal.

3.9 THE INDEPENDENT PRICING AND REGULATORY TRIBUNAL AND THE COST RECOVERY OF NSW WATER SERVICES

The Independent Pricing and Regulatory Tribunal (IPART) of NSW is the body responsible for setting maximum prices for water services provided by the State Water Corporation and the Water Administration Ministerial Corporation (WAMC), the current bulk water supply authorities for NSW. IPART has been responsible for regulating bulk water prices since 1996, setting prices to reflect the costs of water supply consistent with Council of Australian Government (COAG) water reform framework. Prior to 2001, the Tribunal set the water prices for the former Department of Land and Water Conservation (DLWC), which had been the sole manager of NSW bulk water services. The Department has since been restructured, replaced by two separate bodies State Water Corporation and the Department of Infrastructure, Planning and Natural Resources (now Department of Natural Resources – DNR). This restructuring was necessitated by the cost-recovery process, where a more transparent cost base for the bulk water services of the former DLWC was needed to determine efficient water price setting (IPART 2004).

State Water is governed by the State Water Corporation Act 2004, and has the primary role of managing all of the NSW bulk water delivery functions on regulated rivers, outside of areas operated by urban water authorities including the Sydney Catchment Authority, Sydney Water Corporation, and the Hunter Water Corporation. State Water releases flows from its dams into rivers to be accessed by its customers, including irrigation corporations, country town water supply authorities, farms, mines, and electricity generators. The delivery of environmental flows is also part of State Water's operations (SW 2005).

The Water Administration Ministerial Corporation (WAMC), created under the former Water Administration Act 1986 (*WAA 1986*), is the statutory entity through which the designated NSW government Minister delivers its water resource management functions, including the approval of projects and other administrative matters. It is through the WAMC that water management policies are designated to DNR (PC 2003).

IPART sets separate maximum prices for State Water and DNR's water resource management activities in supplying bulk water to users from regulated, unregulated and groundwater sources. Submissions made by State Water and DNR detailing pricing proposals form the basis on which IPART sets prices for cost-recovery. The proposals detail the projected costs incurred by each authority in supplying water and providing water supply facilities, and must be justified with comprehensive financial information (IPART 2004). An independent consultant (ACIL Consulting carried out the 2001 determination) is then commissioned to assess the efficiency of State Water and DNR's projected operating and capital expenditures.

The pricing structure for services is a two-part tariff, comprising of a fixed-charge based on volume entitlement and a usage charge per megalitre extraction. The fixed-charge component allows for some revenue stability, while the usage charge is consistent with user-pays and efficiency objectives. This two-part tariff configuration applies to both State Water and DNR pricing structure. The total charge set for regulated rivers is the sum of costs for the two authorities' water services, while unregulated and ground water systems only incur DNR service charges because there are no dam operation costs. Irrigators in unregulated systems are charged a flat-fee until metering is in place, in which time a two-part tariff is charged (IPART 2004).

The latest price determination was made in August 2006 for prices applicable up to June 2010. In one of the earlier determinations in 2001, the Tribunal had increased charges for regulated rivers by up to CPI+15% per year, and unregulated rivers up to CPI+20%. In the following IPART determinations, it was estimated the price level for most regulated valleys the prices are close to full cost recovery level. In the 2005 determination, prices in valleys which achieved full cost recovery are adjusted to the CPI to maintain current prices in real terms (IPART 2005). An example of the structure of prices set for water systems is shown in Table 3-1, which applies to the Namoi Valley in NSW (IPART 2006 p.15 and 135).

Table 3-1: IPART price determinations for Namoi (source: IPART 2005 p. 17).

Institutions	Regulated			Unregulated	
	Entitlement Charge		Usage Charge	Entitlement Charge	Usage Charge
	High security	General			
SWC Entitlement Charge ($/ML)	8.04	5.36	6.42	-	-
WAMC Entitlement Charges ($/ML)	2.62	1.75	2.09	2.30	1.53
Total $/ML	10.66	7.11	8.51	2.30	1.53

Current pricing determinations are designed to recover relevant water resource management costs and for demand management, rather than to address environmental externalities. There has been no pricing provision to encapsulate the environmental costs of withdrawing water from the water sources; the only costs relating to environmental protection are State Water operations including the installation of fish ladders, mitigating thermal pollution, and releasing environmental flows (IPART 2005). While the two-tiered system has the effect of sending water conservation signals, bulk water charges make up a relatively low proportion of consumers' bills. Unless prices are significantly increased, water consumption is unlikely to fall to environmentally sustainable levels pursued in the COAG Water Reform and National Water Initiative 2004. However, a high usage charge for water may devalue water entitlements, since the value of ownership over rights to extract water from the flow of benefit from its use (Goesch 2001).

3.10 SUMMARY OF CHAPTER 3

In this chapter, the suite of institutional arrangements in Australia's water economy has been presented. The transition between the 'expansionary phase' and the 'mature phase' of the water economy is evidenced by the increasing cooperation between States for the sustainable management of water resources, beginning in the 1990s. This was followed by a series of intergovernmental agreements, with growing focus on the environmental aspects of water. However, progress to implement the strategies outlined by the agreements has been slow, and arguably inadequate. The cost associated with achieving various environmental targets, for example in the National Water Initiative and Living Murray Initiative, do not appear to be well justified on economic or ecological grounds. The revenue allocation to achieve the targets and the target itself also seem to be chosen out of convenience rather than based on rigorous evaluation. The determination of an 'efficient' target and the best way to achieve it, however, is difficult. The implications of various water policies and the complexity of water management are discussed further in the following chapter, in which a review of literature on the different aspects of water management is presented.

Chapter 4.

LITERATURE REVIEW

In previous chapters, the evolution of Australia's water economy and its institutional arrangements were analysed. This forms the foundation for this chapter, which reviews literature relating to problems faced in water management. The intention of this chapter is to present the current state of the art in analysing the complexity of moving towards efficient reallocation of water between competing uses.

4.1 CATCHMENT MODELLING – AN INTEGRATED APPROACH

A general trend in water (and environmental) management has been the shift towards interdisciplinary treatment of the problems (Bjornlund 2003a). This shift in doctrine evolved from greater appreciation of the hydrological, ecological, economic and social aspects of water resources, such that a more 'sustainable' use pattern may be established, and to achieve this efficiently via economic instruments (Rolfe 2005). It is therefore appropriate that the interdisciplinary approach is increasingly common in natural resource management, involving a mix of physical, social, economic and ecological perspectives (Jakeman et al. 2005). In economics literature, the amalgamation of economic and biophysical information may be classed as bio-economic modelling, which links environmental outcomes with economic performance. These models are useful for predicting the costs associated with various environmental settings, providing information for more efficient resource management options to be forged (Bennett 2005a).

However, there appears to be a lack of such efficient solutions being implemented. This is evidenced by the relatively ad hoc environmental policies, whereby the targets and revenue allocation for achieving the target seems to be chosen out of expediency. Two significant examples include the Living Murray First Step Agreement to spend $500 million to provide 500GL of water over five years (MDBC 2007c); and the $10 billion

National Water Plan over 10 years, one-third of which will be spent to buy-back entitlements (Howard 2007). Efficient targets should be set such that the last unit of water allocated to the environment equals its marginal value in its next best extractive use. Current arrangements most likely deviate from such efficient allocations (Freebairn 2003), which may be an artefact of the high transaction costs associated with acquiring information regarding the trade-off between extractive and non-extractive uses.

Methods such as non-market valuation help bridge the information gap regarding efficient targets, by eliciting the willingness to pay (WTP) for a bundle of environmental goods. The WTP obtained provides a measure of the social benefit derived from a certain level of environmental protection, and can be used to determine the trade-off between alternative water uses. However, the process is expensive and results are non-transferable, partly due to the inconsistent way data are collected, and the scarceness of available studies (Rosenberger and Loomis 2003). Bio-economic models present a relatively less costly way of estimating the trade-off between different uses of resources (extractive and non-extractive), although the focus has generally been on cost assessment (Bennett 2005a). Ideally, the efficient allocation of resources could be determined through a combination of non-market valuation and bio-economic methods. One notable case, which has incorporated choice-modelling data into bio-economic modelling is Mallawaarachchi and Quiggin (2001), however this seems to be an isolated case.

A number of models have been developed for examining the optimal allocation of irrigation water, through the combined use of biophysical simulation and mathematical programming (e.g., Grismer and Gates 1991; Gretton and Salma 1997; Caswell et al. 1990; Heaney et al. 2001; Powell et al. 2003; Aluwihare et al. 2005; Ancev et al. 2004; Letcher and Jakeman 2002; and others). While there is a range of such 'bio-economic' studies, to the best of the authors' knowledge, most of these have been based on representative farms and often estimate costs on a farm-basis, or rely on representative equations for spatial factors and physical relationships which are fairly inconsistent across different studies. In addition, certain hydrological and biophysical links are excluded perhaps for ease of assessment or for focusing on specific cause-effect relationships.

There is now a range of advanced computer models available which can capture the biophysical relationships in an environment. The advance of computer technology has contributed to the improvement in the study of these spatial relationships, especially with the development of Geographical Information Systems (GIS). However, the use of GIS in resource economics research appears to be limited, particularly within the framework of optimisation economics. In the US, there has been significant drive to stimulate economic research incorporating remotely referenced information since 1992, with funding from US EPA spurring the development of integrated ecological and economic analysis, for the Patuxent catchment in Maryland (Ancev and Odeh 2005; Voinov 1997). The greatest applications of GIS information in economics, however, seems to be in hedonic pricing and spatial econometrics, in quantifying the significance of spatial dependence between e.g. socio-economic variables within regions (e.g. Bateman et al. 2002; Bockstael 1996; Doss and Taff 1996; Clapp et al. 1997).

The use of GIS based biophysical models in Australian economic analysis is also limited, but growing. For example, Nordblom et al. (2007) uses GIS layers of landuse and soil type to generate biomass production using the plant growth model named APSIM; Mallawaarachchi and Quiggin (2001) incorporate GIS in the bio-economic simulations for cane growth, also using APSIM; Bennetton et al. (1998) predict the spread of fire across a terrain using GIS layers, feeding into a benefit-cost analysis of fire fighting in Victoria. There is also good potential for its use in benefit transfer for drawing comparisons between attributes at target sites and existing studies (Troy and Wilson 2006; Ancev and Odeh 2005).

However, a particular area of neglect in these biophysical models has been in the realm of groundwater hydrology. Although models like APSIM are versatile in its ability to "plug in / pull out" sub-modules as required (McCown et al. 1996), the model does not appear to have strong hydrological components linking soil type to groundwater hydraulics. The hydrological model most adopted in NSW is the IQQM, which was developed by the Department of Infrastructure, Planning and Natural Resources and has been used as the basis of Water Sharing Plans (WSP). It estimates the movement of water throughout a river system, based on information on inflows, extractive demands, soil information, and water management rules such as the WSP (Hameed and O'Neill 2005). However, this model also lacks any links between groundwater and surface water systems, as well as crop effects associated with climate (Letcher and Jakeman 2002). One of few economic studies to incorporate a comprehensive geo-hydrologic component is the catchment modelling approach presented in Hatchett et al. (1991). Generally, this model has a similar functioning to a more widely used model, the Soil and Water Assessment Tool (SWAT), which disaggregates land parcels according to soil characteristics of the catchment with links to surface and groundwater hydraulics.

In the present study, the Soil and Water Assessment Tool (SWAT) hydrological model was used to model the Mooki catchment. This geographic information systems (GIS) based model was created by the USDA Agricultural Research Service and has been widely applied to catchment management problems (Neitsch, et al. 2001). The model has been used to map large catchments with spatially varying physical characteristics. These include processes such as water movement, sediment movement, crop growth, nutrient cycling etc., using input data of weather, soil properties, topography, vegetation and land management practices in the watershed. While the model is data intensive, it provides a high degree of spatial detail because of the model's conjunctive use of GIS. An additional advantage is its geo-hydrological component, which links the surface and groundwater systems with landuse and soil profiles. The model does not rely on regression equations to describe the input and output variables; instead it uses specific physical processes to predict impact of land management practices in large, complex watersheds (Neitsch et al. 2001).

The SWAT model has been adopted in a handful of economic studies. A catchment management framework which incorporates the use of spatially referenced data from SWAT is presented in Ancev et al. (2006), to generate optimal solutions to resource use on a site-specific level. Tanaka and Wu (2004) used SWAT to simulate the changes in crop production associated with various nitrogen reduction targets, and derived the costs associated with pollution targets. In Whittaker et al. (2007), the SWAT model is integrated with a generic algorithm to iteratively determine optimal solutions and trade-offs between alternative conservation practices for a watershed. This allows for resource changes from upstream use to feedback into downstream decisions. However, such an approach is laborious and computationally expensive, requiring the use of clusters of 'slave' processors linked through a generic algorithm to reduce the time for convergence. The evolution of GIS-integrated optimisers in Australia may have been hindered by the limited programming expertise and computational requirements for such algorithms, especially those with complex feedback mechanisms.

Nevertheless, the use of a GIS-based economic optimisation framework allows for more accurate assessment of the potential outcome of catchment policies, although perhaps not at insignificant cost and complexity. The treatment of water related issues at a catchment level, based on spatially explicit data from GIS allows the optimal distribution of agricultural activities to be determined, as well as the optimal distribution of water resources. Furthermore, the use of average parameters (e.g. deep drainage coefficients, crop yield, irrigation etc) to analyse inherently heterogeneous landscapes can result in blanket policies that may cause significant inefficiencies (e.g. Greenville and MacAulay 2006; Varela-Ortega et al. 1998). Using a GIS-based biophysical simulation model, the parameters in this thesis are treated on a site-specific basis and at a high level of spatial detail, which allows for a more precise analysis of the social-economic values of water on a catchment scale. It also leaves open the prospect of incorporating non-market valuation into this analysis as future work.

4.2 MARKET-BASED INSTRUMENTS

A number of instruments have been used in natural resource management, including taxes, standards, and, in particular, cap-and-trade which is thought to be more politically favourable (Weber 1999). This decentralised means of resource allocation is preferred because it is postulated to achieve better outcomes by eliminating the transaction costs incurred through centralised agencies (Tsur and Dinar 1995). The water market has been promoted as part of the water reform to achieve efficient solutions, by allowing water to reallocate to its true value (under perfectly competitive conditions). An efficient water market is also thought to reduce the opportunity cost of environmental flows significantly, by allowing environmental water to be sourced from the least profitable irrigation activities (Heaney et al. 2002). However, it appears that water markets in both developing and developed countries are far from the theorised ideal, in which they are able to increase allocative efficiency and to reduce the burden of improving environmental quality. There are often institutional, political, and physical barriers that prohibit the full functioning of water trade and a competitive market. In an imperfectly developed market, potential traders are faced with large transaction costs when entering the water market, including the gathering of market information, finding potential trading partners, legally effecting transfers etc (Carey et al. 2002). While Australian water markets have some formal trading arrangements (e.g. trading platforms including Water Move and Water Exchange Australia), there remain impediments such as poorly defined property rights, uncertainty in supply, infrastructural impediments, excessive transaction and transfer costs, and speculative hoarding behaviour. These factors have effectively deterred irrigators from participating in trade, precluding efficient water markets and limiting the opportunity to source environmental flows at low cost (Crase et al. 2000).

Furthermore, there are often administration fees and commissions to process transactions by water authorities. Many irrigation authorities also actively prohibit inter-valley trading to guard against stranded assets (Goesch and Beare 2004). These factors confine water to be transferred in local markets, which have relatively lower transaction costs because there are less legal and bureaucratic restrictions compared to inter-regional trading (Easter et al. 1998). In addition, transfers are more efficient since there are less transmission losses where water does not need to travel long distances (Carey et al. 2002). Local trade therefore has some advantages over inter-regional trade.

The management of diffuse source pollution through market-based instruments also exhibits significant market failure, due to the considerable transaction cost required to accurately measure its occurrence. Deep drainage is a diffuse source pollution associated with water use and carries salts through the soil profile, contributing to salinity. Some deep drainage is required to carry salts out of the soil profile to avoid salt build-up, which should be at the natural rate provided by rainfall. Too much drainage, e.g. from irrigation, can cause groundwater levels to rise and increase salinity risk (Silburn and Montgomery 2005).

Caswell (1991) highlighted the detrimental effect of polluted drainage waters – which become return flows – as a potential problem to downstream irrigation. However, the cost for the upstream producer to minimise deep drainage may be greater than the benefits to the growers downstream. The 'efficient' level of deep drainage should depend on the cost of reducing deep drainage and whether the quality of return flows has an effect on crop growth. On the other hand, while deep drainage is generally regarded as detrimental to agricultural production, it can also provide benefits to downstream users. Heaney and Beare (2001) found that the improvement in irrigation efficiency upstream has implications for the volume and quality of water downstream, transmitted through the reduction of the level of return flows that contribute to surface and ground water supply. In this way, deep drainage can have both positive and negative effects on downstream water users. If water quality has negligible effects on crop growth, then the upstream user should only reduce deep drainage to the extent where downstream supply is not affected.

It is considered optimal to create exclusive property rights over resources in order to contend with market failures inherent to 'common-pool-resources', with one instrument corresponding to one objective (Tinbergen 1950). However, because water use and deep drainage are linked, it may not be efficient to have separate instruments for their control. Weinberg et al. (1993) examines the extent to which water market in its own right could contend with water quality (salinity) problems. This study shows that introducing water trade can lead to an overall reduction in water use and by associated deep drainage, although this is not necessarily the least-cost solution that can be achieved. Nevertheless, the difference in benefit between a targeted deep drainage reduction policy compared to a water reduction policy, is only of a small magnitude; the cost of acquiring accurate information regarding discharge points in order to implement drainage policies may involve transaction costs that outweigh any difference in efficiency between an optimal set of input taxes and a water market. This finding is reiterated in Legras and Lifran (2006). The authors model irrigation-induced salinity under different market designs, in the form of a water diversion cap, and two decoupled markets for diversion caps at the basin level and recharge caps at the zone level. The findings imply that a catchment-level water diversion market would be more efficient in managing coupled externalities. Caswell et al. (1990) also suggested that using water-pricing policies might be more effective than deep drainage pricing to induce changes in irrigation practices. This conclusion was drawn from the finding that the effectiveness of drainage pricing on technology switch is low relative to water pricing. This is simply because the volume of water applied is higher than the volume of drainage generated in irrigation.

The potential to use a cap-and-trade scheme as a means to effectively manage recharge, is examined in Whitten et al. (2005), which studies the use of tradeable recharge (deep drainage) credits in Coleambally Irrigation Area. It was found that introducing a recharge cap-and-trade scheme would provide a relatively small gain, and hence small farm scale benefits. One significant obstacle identified by the authors is the diffuse nature of recharge, which is different to other cap-and-trade models where the pollutant is point-sourced and measurable. It is difficult to link the drainage occurrence to one distinct origin due to the spatial and temporal variation in its occurrence. The conclusion was that usual cap-and-trade models are not likely to generate sufficient benefits to drive its full adoption, in addition the expectation that the full gains from trade will not be realised in practice. Another alternative is point/non-point source credit trading, which has been implemented in some catchments in the US (Horan 2001). Under this system, point source polluters are able to purchase additional credits from non-point polluters at a given conversion rate. However, the trading ratios, for which non-point source credits are converted to point-source pollution, is subject to significant uncertainty. This is because the rate at which non-point loadings are reduced is regarded as an imperfect substitute for point-source loading reductions. Furthermore, the market requires that non-point and point-source polluters coexist in a basin for it to be effective.

While salinity standards have been set for NSW catchments, as part of the Murray-Darling Basin Salinity Management Strategy, the practicality of a widespread salinity-capping scheme is therefore in question. The diffuse nature of deep drainage makes it costly and difficult to quantify, not to mention the expense of instruments used to measure deep drainage, e.g. lysimeters (Triantafilis et al. 2003). The time lag between when deep drainage becomes recharge to the shallow groundwater table also adds to the complexity in accurately measuring its incidence. While there are now separate and tradeable water entitlements to promote efficient allocation, the use of market-based deep drainage instruments has not been widespread. Proposed deep drainage reduction policies have ranged from voluntary best management practices (e.g. on-farm storage lining) to district-level drainage (salinity) restrictions (e.g. Basin Salinity Management Strategy). A number of papers recognised deep drainage occurrence as being contingent on technology and soil quality (Ancev et al. 2004; Caswell et al. 1990; Khanna et al. 2000). These authors advocate the use of pollution taxes and the adoption of efficient technology as the best means to provide conservation incentives for polluting inputs (deep drainage). However, the appropriate salinity control measure is likely to vary from basin to basin, depending if salinity (deep drainage) is a persistent problem in the region.

4.3 HYDROLOGICAL ISSUES – RETURN FLOWS

Some literature cautions against relying on modern irrigation systems as the solution to conserving water in river basins altogether. Scheierling et al. (2004) and Huffaker and Whittlesey (2000) suggests that promoting water efficient technologies without regard for overall basin hydrology may lead to adverse outcomes for the basin due to the contribution return flows make to downstream water supply. Scheierling et al. (2004) stresses that unconsumed water becomes return flows that contribute to downstream water supply, so reducing deep drainage through improvements in irrigation efficiency would only result in a fall in irrigation water for downstream users. By this reasoning, policies encouraging the use of efficient irrigation technologies would have limited effect on generating real increases in surface water. However, it is intuitive that in-stream flows should increase due to a reduction in direct water extractions, thereby compensating for the fall in return flows. In addition, reducing return flows, and hence deep drainage, would mean improved water quality in terms of diminished salt content and salinity.

It is also true that if the irrigator becomes more water efficient, and in the absence of water market, the water conserved would simply be used to expand production if the producer has idle land. The outcome would be a net reduction in basin water supply since the same volume is being extracted but less becomes return flow due to improved irrigation efficiency. Huffaker and Whittlesey (2000) contend with this effect of reduced downstream supplies by factoring in the opportunity cost of improved upstream irrigation efficiency. The net benefit of improving irrigation efficiency at a location upstream is measured against the foregone benefit of decreased irrigation return flow downstream, and the desirability of any improvement in upstream efficiency falls as more water become return flows. In essence, both Scheierling et al. (2004) and Huffaker and Whittlesey (2000) suggest that without considering the hydrological relationship in the basin, policies to improve irrigation efficiency may lead to unexpected adverse outcomes.

Water trade and improvements in water use efficiency have similar adverse effects of reducing return flows, which impact on the quality and volume of water used downstream. It has been suggested that a system of property rights for return flows is required to internalise these effects (Heaney and Beare 2001). If return flows are from irrigation areas with relatively low underlying groundwater salt concentration it can provide dilution flows downstream. Water trade or improving irrigation efficiency may reduce these positive externalities because it deprives some areas of beneficial return flows (Heaney and Beare 2001). On the other hand, deep drainage has also been considered as pollution, for example in Caswell et al., (1990). If the recharge is high and ground water salinity is high, return flows would contain high salt concentrations and increase salinity risk. Under such circumstances, if deep drainage is reduced, the amount of saline recharge transported to the river system is also reduced.

Improving upstream irrigation efficiency is thus beneficial only if downstream groundwater salinity is high and groundwater response times are short; defined as “the time it takes for a change in recharge to be reflected in a change in saline discharge" (Heaney and Beare 2001). The aquifer in the Namoi, where the present research is focused, is thought to be responsive to changes in deep drainage (Karen Ivkovic 2005, pers. comm.), meaning the recharge rates are quite high. The recharge time estimated for the Mooki is 17 days (Vervoort 2005, pers. comm.), so the response time is short and water quality changes are realised quickly. Excluding the beneficial properties of return flows in the economic analysis is therefore appropriate for the Mooki case study, since the quality of return flows may generate greater negative than positive externalities by augmenting salinity problems. This is discussed in detail in Chapter 6.

Furthermore, the reduction in return flows on downstream supply should not be an issue if there is the opportunity to substitute this volume from the water market, where it exists. Rather than relying on return flows, the irrigator could purchase water directly from the market, to compensate for the reduced volume. Under these circumstances, the decision to invest in water efficient technologies would not be influenced by considerations of reduced return flows; each irrigator would select the system that maximises their profit. Downstream irrigators who are affected would purchase water allocations from the market if it is profitable to do so. Those downstream irrigators who find it unprofitable would forego the reduced volume and adjust production accordingly. This would allow return flows to be valued explicitly, rather than implicitly through its value in production.

4.4 WATER PRICING AND WATER USE EFFICIENCY

The pricing of water and whether it can improve water use efficiency is a particularly contentious subject. The intention of the cost-recovery process was to better reflect the true cost of supply of water, ideally equating the marginal environmental cost and marginal economic cost. However, significant increases in water prices have implications for equity in access, since the supply of cheap, high quality water has been viewed as a basic right (Godden 1997). It is also politically unfavourable, and users have been able to exert political influence to preclude increases in irrigation water prices (Easter et al. 1998). Some authors also cite the relatively large price increases required to reduce demand, which would also affect low income groups more than wealthier groups (Renwick and Green 2000).

The social implications of water price increases may have contributed to government's reluctance to use pricing policies to manage water demand. Government intervention has typically been through quantitative instruments regulating the level of water use, for example through a Cap on water diversions. In NSW, this Cap is written into Water Sharing Plans as a minimum in-river flow requirement, in recognition of the environment as a legitimate user of water. However, the Cap may not reflect the efficient allocation, since the opportunity cost of production of the water capped from irrigation may not justify the environmental benefits generated. This is due to the relatively ad hoc nature of caps (Freebairn 2003). Therefore, whether price-based or quantity-based water demand management is the most effective means of achieving efficiency targets is debatable.

The use of modern irrigation systems has been advocated as an effective means of achieving water conservation while maintaining profitability. The importance of alternative irrigation systems in achieving water conservation targets has been highlighted in several papers, including Ancev et al. (2004), Bernardo et al. (1987), Caswell et al. (1990), and Varela-Ortega et al. (1998). Bernardo et al. (1987) demonstrate that even with little flexibility in terms of irrigation system choice the investment is worthwhile even in the short run. This finding is also supported by Caswell et al. (1990), and further examines the effect of using water pricing as a catalyst to investing in efficient irrigation technologies. The central argument in Caswell et al. (1990) seems to be that technology choice is dependent only on water price or subsidy and tax combinations, which is enough to spur the switch from one technology to another. If output prices are high then drip irrigation prevails as the most favourable option. However, Varela-Ortega et al. (1998) argues that farmers' choice in technology is not necessarily just price dependent but depends on the agronomic and structural limitations, financial constraints, and to a lesser extent on water prices. This is a conclusion that is coherent to Foley and Raine (2001), who suggested the change in irrigation systems is not necessarily out of economic consideration but simply because of convenience when replacing systems. Additionally, most farmers have preferred sprinkler irrigation to drip systems mainly due to the difficulty in maintaining drip systems (Murray 2004).

A general consensus seems to be that imposing a uniform water pricing system for a water district to meet desired water efficiency objectives is likely to result in considerable economic losses. While higher water prices can spur greater adoption of water-saving technologies, policies must be region specific because a blanket pricing scheme would merely induce small changes in water use but cause significant income loss. Older water districts, where technological efficiency (T.E.) is lower and water demand is more elastic, have different responses to more modern irrigation districts, where T.E. is higher and water demand is less elastic. These two areas have different potentials for water savings as a result of the level of T.E., characterized by the level of water demand elasticity. As a result, an across-the-board increase in water price may only result in net welfare losses and little water savings if localized, heterogeneous conditions are not taken into account when formulating policies for a region (Caswell et al. 1990; Varela-Ortega et al. 1998).

The current water pricing authority in NSW appears to be well aware of such welfare impacts. Cox and Warner (2007) discuss the importance of limiting bulk water charges primarily to recover the operational cost of delivering water, and with a secondary objective of demand management. Conservation signals can be provided through the market price for water would be eroded if water delivery charge were high, since it reduces the flow of benefits received from its ownership. In the presence of water market opportunities, there is a natural incentive to invest in water efficient technologies up to the point where the benefit from water savings equates the capital costs (Ancev and Vervoort 2007).

4.5 EXTERNAL WATER TRADING AND STRANDED ASSETS

A pressing issue is the prospect of external buyers entering a regional water trading system in the near future, which has implications for the cropping industry and may open the possibility of stranded assets. This comes amidst discussions of substantial government buy-backs of entitlements for environmental flows. The Commonwealth

Water Plan announced early 2007 budgeted $10 billion towards managing the MDB water resources, $3 billion of which is allocated towards directly buying-back water entitlements (Howard 2007). There is also the possibility of an expansion of coal reserve mining, a water intensive industry, in the northern region of NSW. The Gunnedah shire overlays one of the largest underground coal reserves in NSW, which stretches 500km from Wollongong and Narrabri, and is 150km wide (Gunnedah Shire 2006). A five-year exploration licence has been granted in early 2006, for exploration and development of coal reserves in parts of the Mooki valley. This has instigated significant community debate pertaining to environmental concerns as well as competition for infrastructure and water, given current plans to substantially reduce surface and groundwater entitlements over the next five to ten years (Strang 2006).

However, unfettered water trading between competing uses is thought to achieve a most efficient outcome, enabling water to trade to its highest value use or sectors (Tsur and Dinar 1995; Carey et al. 2002; Heaney et al. 2002; Goesch and Beare 2004, and others). Some authors advocate for rural-urban trade (Weinberg et al. 1993; Dwyer et al. 2005). This is perceived as an efficient way to improve on the current water allocation system, which has been relatively fixed even though demand has risen more in the industry and urban sectors compared to agriculture (Rolfe 2005).

The benefit of encouraging greater trade between regions is illustrated in Weinberg et al. (1993). They estimated the rural water market price to be less than half the price in urban markets in their Californian case study. This presents an opportunity for useful water transfer between the urban and rural sectors. Rural-urban trade was also examined in an Australian context and estimated net gains to trade were greatest when trade is unfettered between irrigators in south-east Australia and also to townships in interconnected hydrological systems (Dwyer et al. 2005). The greatest benefit could therefore be achieved if transaction costs are reduced to increase the probability of an efficient equilibrium, and encouraging greater trading to external agents outside of the irrigation district or industry (Carey et al. 2002).

However, allowing the entry of an external buyer into the regional water market increases competition for surface and ground water resources. This is in light of significant cuts in groundwater entitlements in the Namoi catchment that are expected over the decade. Resources will become increasingly scarce, as it is likely there would be some reallocation of resources from agriculture to mining or the environment. It is important that the impacts of external agents competing with irrigators for water are assessed, to avoid significant social costs on rural economies dependent on irrigation industries.

A commonly cited reason for restricting trade is because as irrigators leave an irrigation district, a higher cost is imposed on those remaining in the system (Goesch 2001). This is the problem of stranded assets, whereby higher delivery charges are imposed on remaining irrigators as more water property rights are sold outside the irrigation district. In extreme cases the irrigation authority is left with large fixed costs and no customers, so external trading is prohibited by some catchment authorities due to the risk of stranded assets. This has implications for the Commonwealth Water Plan, in which the purchase of environmental flows form a significant portion of planned expenditure. In order to minimise the socio-economic impact of purchases, the government can either enter markets across regions, or by paying an exit fee to prevent high capital costs being imposed on the remaining irrigators in low value areas. Alternatively, a structural adjustment package could be provided to those regions significantly affected by the withdrawal of water (Goesch and Heaney 2003). These considerations again highlight the importance of site-specific analyses, in order to evaluate the economic impacts that arise from government intervention.

4.6 CATCHMENT STUDIES OF THE NAMOI

Key studies pertaining to water reform in the Namoi river valley include Ancev et al. (2004), Aluwihare et al., (2005), CARE (2003), and Letcher and Jakeman (2003). Both Ancev et al. (2004) and Aluwihare et al., (2005) model the profit maximising allocation of irrigation water under limited water supply for multi-crop producers for the Mooki River sub-catchment. Ancev et al., (2004) look at the basin wide allocation of water, while Aluwihare et al., (2005) conducts a farm-level model to analyse the socio-economic costs of proposed Water Sharing Plans (WSP). The novel component of the model in Aluwihare et al., (2005) is that it integrates the existence of on-farm storages, which is an important feature on farms in unregulated rives, and the analysis of uncertainty in production. However, water losses to deep drainage and groundwater hydrology were not considered, although much literature points to these as significant components that need to be incorporated. Nor did it consider the use of alternative, water efficient, irrigation systems and the potential gain in the presence of a water market.

Letcher and Jakeman (2003) analyse the impact of water policies at a basin level, by aggregating the basin into large portions of homogenous regions, according to the area measured by stream gauges in the catchment. Its 'integrated assessment' framework involves a hydrological model that links upstream water extractions to downstream water supply, which feeds into an agricultural production model. The study uses a sophisticated model that focuses on the management of 'off-allocation' water – water that spills from the dams – in the Namoi Valley. Its main shortfall is the lack of a groundwater component, and does not consider salinity impacts or changes in environmental policy. The value of water efficient technologies and the water market were also not evaluated as adjustment options if water resources become scarcer.

CARE (2003) conducted a study of the groundwater WSP on the Namoi catchment, based on representative farms for each Zone in the Namoi. The likely impact of the WSP on these farms was assessed over a 20-year period, using an input-output (IO) analysis to assess the region-wide impact. The data used regarding farmer's production activities and assumptions on economic parameters were very detailed. However, the use of input-output tables has been more commonly employed for analysing the effect of changes in demand for outputs, rather than to measure impacts of changes in resource availability. Furthermore, IO analyses tend to overestimate regional impacts due to the erroneous application of the "value-added" approach to estimate shadow prices of (for example) water, without subtracting the opportunity cost of non-water inputs (Young 2005). It is considered a poor substitute for a full economic analysis, although it is regarded as a cheaper and less controversial option (Bennett 2005a).

Also taking a catchment level approach, Ancev et al. (2004) presents a combined hydrological-economic model to examine the optimal basin water allocation and deep drainage occurrence. The modelling framework proposed in Ancev et al. (2004) involves the use of SWAT, a GIS-based biophysical model, to provide site-specific results. Constraints pertaining to deep drainage were also formulated to examine the effect of policies targeting the level of deep drainage that occur in the catchment. A similar method of analysing the effect of pollution targets is also analysed in Tanaka and Wu (2004). SWAT was used to simulate the changes in crop production associated with various nitrogen reduction targets, for which corresponding marginal profit loss curves were derived. This process is similar to Ancev et al. (2004), but instead of deep drainage targets, nitrogen targets have been set in Tanaka and Wu (2004). Based on this methodology, marginal profit/loss curves could be obtained for any desired environmental constraint, including environmental flows. These two studies form the basis of the modelling framework adopted in this thesis.

4.7 SUMMARY OF CHAPTER 4

In this chapter, a literature review of the published work in the field of water management and the physical complexities involved has been presented. From this review, the issues relating to the case study are highlighted for the purposes of building an appropriate model for this thesis. Using an integrated biophysical and economic modelling approach, simulations from the biophysical model, SWAT, will form the basis of an economic optimisation model in this thesis. Rather than modelling a representative farm, site-specific, spatially referenced information of the case study of the Mooki basin in the Namoi valley is used. Using this approach, the model provides realistic results that are directly applicable to the basin. It also has an advantage over modelling a representative farm because of the heterogeneous nature of catchments. This is because blanket policies devised for a representative farm may be ineffective or lead to significant social costs, e.g. large income losses for small changes in resource use (Varela-Ortega et al. 1998). The optimisation process is conducted from a catchment perspective constrained by environmental targets and water supply limits, which would allow more insight into the impacts of various environmental policies and how irrigators could adjust to them at the least-cost.

In the following chapter, the specific model used in this thesis is presented. The model specifications, in terms of the linear programming and dynamic programming components, are examined in detail. This includes a discussion of the theoretical solutions to water allocation based on this modelling framework, which are in accordance with economic efficiency.

Chapter 5.

ANALYTICAL FRAMEWORK

In this chapter, the economic model used to determine efficient resource allocation for the case study, the Mooki basin, is presented. The optimisation process involves finding the resource distribution that maximises social economic welfare from a catchment manager's perspective, given resource constraints and environmental objectives. The solution provides profit maximising production mix for various water availabilities, in the incidence of government policy changes or increased competition for water.

5.1 SOCIAL OPTIMISATION v PRIVATE OPTIMISATION

There are two ways to model basin water allocation. One way is to determine optimal water allocation from a catchment manager's perspective, and the other is from an individual irrigator's perspective. The optimisation process from both viewpoints is similar, since each would have a common objective to maximise net benefit from production subject to resource constraints. The main difference is that a catchment planner would have the aim of maximise social wellbeing, an integral part of which involves maximising profit to farmers. This is done by distributing water according to its value at the margin across different users. From a private perspective, the opportunity cost of resource use is confined to the farm-level. The water scarcity rent and externalities which have not been priced, in the form of salinity and return flows, are not internalised in the private irrigator's water allocation decisions. As a result, a model simulating individual profit maximising objectives may generate results that deviate from what is socially desirable, due to the discrepancy in the opportunity costs included in the objective. There would be undeniable benefits from an approach that examines behaviour of individual producers, since results from such an analysis could be used to predict the effect of policy. However there remains the need for a policy direction towards socially optimal outcomes, which would not be the case when the problem is only examined from the perspective of individual producers. It is therefore useful to model from a social