Articles and Notes

Water Allocation and Supply Reliability in the Murrumbidgee Valley

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The objective of this study is to determine the average annual income and income variance of alternative irrigation water allocations and associated supply reliabilities in the Murrumbidgee Valley. Traditionally, water supply authorities have aimed to supply irrigators with their full allocations in all but the most severe drought years. This means that a substantial amount of water is held in storage as a reserve and in most years it is not utilised for irrigation or other, including environmental, purposes. In a climate where maximum economic returns for resources are required, water supply authorities are now reconsidering this policy of high reliability with a view to expanding water use for agricultural and environmental purposes.

This study uses linear programming, combined with a hydrology simulation model developed by the NSW Department of Water Resources, to analyse various water allocation scenarios for irrigation and their associated supply reliabilities over a 99 year simulation period. The results of the study indicate which levels of water allocation and supply reliability increase regional net income and lead to changes in revenue variance. Depending on society's trade-off preference for income and income variance, an optimal water allocation and supply reliability can be determined.

1. Introduction

1.1 Background to the problem

The reallocation of existing supplies of irrigation water is becoming an issue of importance as most Australian water economies enter a more 'mature' phase of development (Randall 1981). No longer can water be considered a cheap and plentiful resource. The marginal cost of providing additional units of this resource can be expected to increase significantly in relation to that of the past, as low cost storage sites have already been developed.

A number of supply and demand management measures have been proposed to aid in the efficient allocation process. A useful supply management measure is the manipulation of the reliability of supply by adjusting the total amount of water allocated for a river system.

While there is a case for quantitative consideration of optimal or acceptable levels of reliability for water supply systems from an economic point of view, there has been little formal use of empirical economic evaluation techniques for a number of reasons. First, the need to consider optimal reliability has arisen only as Australian water economies have entered a mature phase of development with a result that existing supplies have become fully committed and the cost of developing new supplies has become more expensive. Second, complex issues are involved, particularly as public benefits may be maximised at reliability levels well below those that maximise benefits to individuals. Third, lower reliability conflicts with the original objectives of schemes which were justified as high reliability or 'drought proofing' measures. Fourth, lower reliability levels may impinge on the financial receipts of water authorities and result in wide variations in receipts from year to year.

No longer can the above stated impediments to studying optimal reliability of water supplies be considered valid. The adoption of reliability levels that maximise economic benefits will become more important as the requirements for reallocation of existing supplies increases.

1.2 Objective

The basic objective of the study is to quantify the

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annual net income and income variance of alternative water allocation and supply reliability policies in the Murrumbidgee Valley.

The Murrumbidgee Valley is a major irrigated region in southern New South Wales which has traditionally had a much higher supply reliability of irrigation water than other irrigated river valleys in New South Wales. The question has been raised whether the provision of such a high current level of water security is socially optimal.

The study involves examining the trade-offs between a system with high reliability but lower average regional benefits and a system with lower reliability but higher average regional benefits. The variance of returns in the latter situation may be expected to increase significantly, so a long time horizon is necessary for the analysis.

2. Efficient water allocation and supply reliability

A regional water economy can be characterised as being in an 'expansionary' or a 'mature' phase (Randall 1981). In an expansionary phase the marginal cost increments in water supply rise only slowly over time, if at all. The water economy operates on the very elastic segment of the supply curve for suitable sites for water impoundments, river modifications, and irrigation developments. As the demand for water increases, existing surplus capacity is utilised, or new projects can be implemented to increase the quantity supplied with little increase in real average cost. A feature of an expansionary phase is the public subsidisation of resource development where the political environment encourages such projects. As the stock of water impoundments and irrigated lands is in a new condition, problems associated with a mature phase such as reservoir siltation, rising water tables, salt damaged lands, and saline return flows into river systems remain relatively insignificent. Competition for water among the various users (agricultural, urban and recreational) is not a significant issue as demand can be alleviated by new projects.

In a mature phase the water economy is characterised by sharply rising incremental costs of supplying water, and greatly increased interdependencies among water users. There is more intense competition for water supplies which expand slowly, and the aggregate effects of individual water use decisions include rising watertables and increasingly polluted and saline effluents. The Murray-Darling Basin typifies this situation, where in parts there is now considerable conflict between agricultural, urban and recreational users. Also there are significant problems of water pollution and land degradation and there is a need for rehabilitation of aging reservoirs, water delivery and drainage systems.

Australian public water policy during the expansionary phase focused on the supply side of the production process, in what Watson, Reynolds, Collins and Hunter (1982) termed a 'requirements' approach. As demand for water increased, this was met by the construction of additional storages. As the water economy enters a mature phase, however, the efficiency of management of existing agricultural water supplies becomes an issue of greater importance than the expansion of irrigation capacity. The perceived view that water is an abundant resource and that extra demand can be satisfied by the development of further storages is no longer valid. Most of the feasible water storage sites have already been developed and the real costs of developing incremental supplies are now much higher than those incurred previously.

The issue of reallocation of existing supplies is an area of major concern to water supply planners. Two approaches to this problem which focus on the demand side are water pricing and markets in water.

Irrigation water supplies in New South Wales have had a long history of public subsidisation, whereby water has been priced at values well below the long-run marginal cost of supply. The efficient allocation of water requires that the marginal units of water delivered be priced at their marginal cost (Warford 1968). Although recent attempts have been made to correct some of the disparity between the actual charge of irrigation water and its true marginal cost (Murrumbidgee Irrigation Areas and Districts Management Board 1990), this still remains a major impediment to efficiency.

Establishing a market in delivered water, which focuses on opportunity cost rather than resource cost, is an alternative to efficiency in water resource allocation. A marketable water rights system would result in the pricing of water to users at its opportunity cost.

The major shortcomings of water markets are that property rights are difficult to define with precision and that they may not necessarily take into account the third party effects on those adversely affected by a market exchange.

Supply management measures, particularly reliability of supply, can also play an important role in the allocation process. Knowledge of the optimal reliability of a regulated river basin under the control of the supply authority will assist planners to identify those basins where major water allocation and supply mismatches occur (Verdich and Bryant 1985). An inappropriate irrigation supply reliability in a river basin may mean a net social loss of millions of dollars per annum.

Water supply systems are typified by stochastic supplies and demand in that knowledge of climatic, hydrologic, economic and social behaviour, and predictions regarding future performance are always subject to error. A failure state is defined as one in which stochastic system performance levels are judged to be unsatisfactory (Kuczera 1987). Reliability of irrigation supplies is just one measure of the propensity of the system to fail.

There are a number of definitions of reliability. Hashimoto, Stedlinger and Loucks (1982) define reliability as the frequency or probability, α, that a system is in a satisfactory state:

$$\alpha = Prob\ [X_t\ S]\ .$$

where X_t is a systems output state, and S is a set of all satisfactory states. Dudley (1975) defines a reliable system as being one in which farmers receive the quantities of water they desire at the usual price in a large percentage of seasons. Another definition of reliability is the probability that no failure occurs within a fixed period of time, often taken to be the planning period (Hashimoto, Stedlinger and Loucks 1982). An additional definition of reliability is one minus the probability of needing to reduce irrigated crop area below the maximum area possible, either by planting a lesser area at the start of the season or by abandonment to rain fed status during the year.

In this study, supply reliability is taken to be the percentage of years that irrigators receive their full allocation[1] (that is 100 per cent). Supply reliability is only a measure of the frequency of years that full allocation occurs. It gives no indication of water availability in those years which have less than full allocation. A measure called 'average allocation' percentage (average of actual announced allocation) better describes the average of the total irrigation water available. To adequately describe system reliability it is desirable to use more than one quantitative measure.

Supply reliability is a function of stochastic supply and demand influences. The demand for water may be considered in terms of the total volume to be supplied over a given period, which may be daily, weekly or annually. Demands for irrigation water can vary from one period to another due to climatic influences (wet periods particularly reduce the demand for irrigation water), and the mix of crops grown in response to various market forces. Some crops, such as rice and lucerne, have significantly higher water requirements than many others and any changes in their total area will affect overall irrigation water demand. The main source of uncertainty in supply of irrigation water is seasonal conditions. The seasonal effects can have temporal implications, for instance, a period of drought can seriously affect irrigation supplies in following seasons due to a possible drawdown on water storages.

Supply reliabilities can have differing impacts upon individuals and the state economy. An individual farm income is related to water supply reliability; as the reliability of irrigation supply decreases, average annual farm income decreases and income variability increases. Supply reliability declines as the total volume of licensed allocations increase.

[1] The term allocation is used to represent the irrigation entitlement of farmers. A volumetric allocation system operates in the Murrumbidgee Valley, where the volumetric allocation relates more to shares in available water than an absolute quantity.

From a state economy viewpoint, due to the increase in the volume of allocation, total regional income generally rises from all farms receiving irrigation.

Howe (1990) identifies a number of criteria by which allocation institutions might be assessed. These are (a) flexibility in the allocation of existing water supplies; (b) security of tenure for established users; (c) confronting users with the real opportunity cost of the resource; (d) predictability of the outcome of the process; (e) equity and fairness in the allocation process; and (f) the allocation process must be capable of reflecting public values that are not considered by individuals.

A system of property rights which satisfies these criteria would be 'non-attenuated', in other words they would be fully specified, they would be exclusive, they would be enforceable and enforced, and they would be transferable.

Within the context of contemporary water allocation doctrine, knowledge of the optimal level of reliability is an essential requirement for the specification component of a non-attenuated set of irrigation water rights. Determination and implementation of an optimal water supply reliability is viewed as a complementary, rather than a substitute, measure to marketable water rights and marginal cost pricing to obtain a Pareto-improvement in the Australian water economy.

3. Trade-offs between water resource systems with differing objective functions

Traditionally, water supply authorities have aimed to supply Murrumbidgee irrigators with full allocations in all but the most severe drought periods. Drought proofing of agriculture has been a common justification for the establishment of irrigation schemes in Australia (Davidson 1969). This means that as high a degree of reliability of water supply as possible has been maintained. An alternative way of expressing this objective is that authorities have attempted to minimise the revenue variance of irrigated agriculture. This clearly advantages individual irrigators but may not realise the maximum potential economic efficiency of the supply system.

Davidson states that irrigation has failed in its objective to stabilise production during drought, as the decline in irrigated production during drought is just as severe as that in dryland areas. He comments (p.154) that "a policy of optimising returns from irrigation schemes can only be achieved if the policy of attempting to supply farmers with irrigation water during drought periods is abandoned. The two aims of maximum economic efficiency and drought prevention are mutually exclusive". If society's aim is to maximise economic efficiency, the optimum irrigation area should be calculated and a flexible system adopted of selling water which does not attach a definite amount of water to any particular piece of land. The optimal area must be allowed to adjust to changes in price levels, costs and technology, if economic returns are to be maximised in the long run.

Dudley (1975) determined that for one case study, average annual net revenue could be approximately doubled by moving from the area at which revenue variance was minimised to a much larger area at which average annual revenue was maximised.

The trade-off problem as presented by Dudley is illustrated in Figure 1. The area developed for irrigation is represented on the horizontal axis while the annual net revenue and net revenue variance are shown on the vertical axis. The area *OA* represents the maximum area that can be developed for irrigation, and *OM* and *OL* are the annual net revenue and net revenue variance if the total area of *OA* remains in dryland use. The line *LA* represents the linear reduction in dryland revenue variance as irrigation replaces dryland production. As the irrigable area increases from zero, annual net revenue increases linearly (irrigation variance is close to zero and thus total variance falls) until a point is reached, at area *OB* and average net revenue *ON*, where the irrigable area is so large that water shortages occur in some dry seasons. As irrigable area expands beyond *OB*, the annual net revenue curve is no longer linear as irrigation variance becomes non zero. The irrigable area could be expanded to *OD* where the maximum annual net revenue occurs is *OP*, however, the irrigation net revenue variance is increasing rapidly at this point. The irrigation water supply at the larger irrigation development levels becomes much less reliable as indicated by the high irrigation net revenue variance. Total net revenue variance is minimised at *OC*. The rational zone for the irrigable area must lie between the range *OC* to *OD* as both total revenue variance and annual net revenue are increasing between these two points. The choice of the appropriate irrigable area depends on the decision maker's trade-off preference between increasing average net revenue and net revenue variance.

4. Methodology

4.1 Study procedure

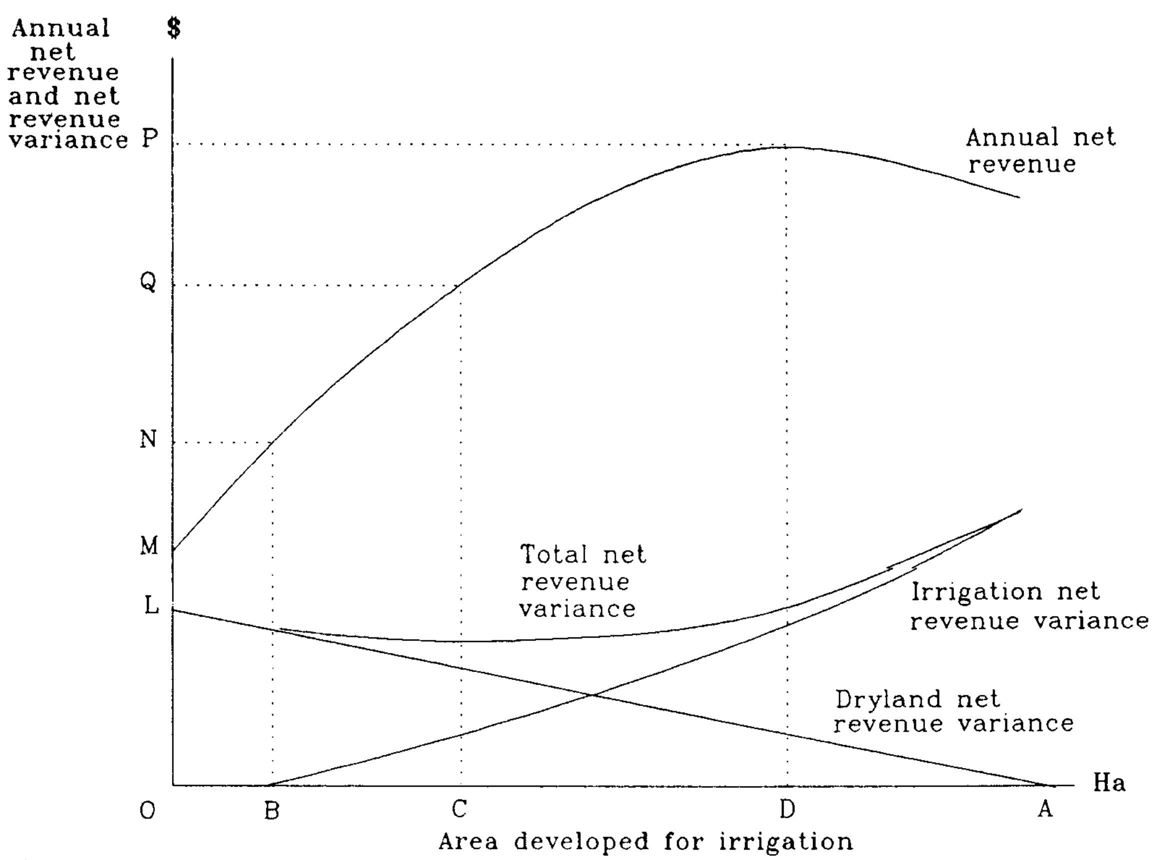
The study uses a combination of hydrology simulation, linear programming and spreadsheet models to analyse allocation and supply reliability issues in the Murrumbidgee Valley with the aim of comparing alternative policies.

A hydrology simulation model of the Murrumbidgee Valley has been developed by the NSW Department of Water Resources (DWR), which contains 99 years of streamflow and hydrological data from 1891 to 1989. This model simulates the DWR's operating rules for allocating irrigation supplies and is used to generate annual announced allocation percentages for various levels of irrigation development[2] (5 per cent increases from the current level), which result in differing supply reliabilities.

Deterministic linear programming is used to calculate optimal annual net returns from irrigated agriculture for a variety of water allocation scenarios. This methodology is considered appropriate as the demand for irrigation water is regarded to be deterministic so only the stochastic supplies need to be captured and this is done through the simulation

[2] Irrigation development is used to describe the area of irrigable land and level of allocation that is regularly used by the licensed holders.

Figure 1: Trade-offs between high and low reliability systems



Source: Dudley (1975)

model. Support for this approach is provided by Dudley (1990) who suggested that there are two Australia's, one lying in the predominantly winter rainfall zone of the higher latitudes, and another covering the predominantly uniform and summer rainfall zones in the lower latitudes. In the winter rainfall zone the summers are very dry, which means that rainfall contributes little to the summer water requirements of plants and the total summer evapotranspiration does not vary much from year to year. From a decision making viewpoint once the pre-irrigation is applied there is virtually no uncertainty of either demand or supply for the immediate year. Uncertainty is essentially limited to supply in later years. Known supply and demand for the immediate season, such as in the Murrumbidgee Valley, permits the use of deterministic, season-long computer-based operations research methods, such as simulation or linear programming models, with a high degree of confidence.

Four regional linear programming models were initially developed to estimate regional net farm income arising from irrigated and dryland agriculture in the irrigated regions of the Murrumbidgee Valley. These models represent the Murrumbidgee Irrigation Areas (MIA), Murrumbidgee Irrigation Districts (MID), Coleambally Irrigation Area (CIA), and private diverters who pump directly from the river. Each of these models are solved for different announced allocation percentages (0 to 120 per cent in 5 per cent increments), with the results from each regional model being transferred to a spreadsheet model.

In addition to changing announced allocation percentages, the private diverters regional model also has the level of volumetric allocation and licensed irrigation area altered. There are 12 levels of increased allocation and licensed area, which are represented by 12 variations in the private diverters regional model. Therefore, a total of 15 separate regional models are solved to generate the required results. These are the MIA, MID, CIA plus the 12 variations of the private diverters regional model.

There is very little potential for increasing the allocation volume and irrigation development in the MIA, MID and CIA due to a lack of suitable land that can be irrigated by gravity flow, restrictions on channel supply and drainage systems and the capital costs of providing additional irrigation infrastructure. Therefore, it is considered that any further irrigation development undertaken in the Murrumbidgee Valley is only possible for private diverters who are located along the river. Furthermore, it is considered that this development is likely to take place mostly between Narrandera and the Murray River.

The spreadsheet model performs as an accounting procedure, which combines the results of the hydrology simulation and regional linear programming models. The hydrology model produces a range of announced annual allocation percentages for a 99 year period for each allocation and licensed area scenario. The net farm incomes for each of the various announced allocation percentages calculated by the linear programming models are incorporated into the spreadsheet. With this information the spreadsheet model calculates the mean and standard deviation of regional net farm incomes for each scenario. The merits of alternative reliability levels can then be assessed by comparing the mean regional net farm incomes and standard deviations for the alternative levels of water allocation and supply reliability.

A potential limitation of this approach is that by adopting static linear programming the analysis assumes that the agricultural plans for each irrigation season are independent of the preceding season. This may not be strictly correct as due to the rotational nature of agricultural production, activities grown in one year may be related to the previous years cropping program. Methods that can be used to overcome this problem include dynamic and recursive programming. Dynamic programming would be computationally difficult due to the number of state variables that may be required which leads to problems with dimensionality. Verdich and Bryant (1985) adopted recursive programming in a study of optimal supply reliability of representative farms in the Namoi Valley and MIA. The two models were run over a 21 year period from 1961 to 1981. This approach was not adopted in this study for a number of reasons. It would considerably add to the computational complexity of the study as in this analysis the period of study is

99 years and, with 15 separate models required to be solved, this would result in a total of 1,485 solutions needed for a single set of results. The approach that has been taken with this research is a computationally easier task, even though it involves 425 linear program model solutions to provide a single set of results. Furthermore, the importance of the independence between cropping years is diminished as a regional programming approach is taken, which involves the aggregation of individual farm models, which masks the effect of changing farm plans between years.

In reality the independence problem is slight as, with the exception of summer cropping programs (soybeans, sunflowers and maize), irrigation seasons can be seen to be independent of each other. Although farmers face a wide range of rotation choices, in the irrigation areas and districts, rotations generally revolve around rice, wheat and pasture. Most farmers do not adhere to specific rotations but tend to vary the areas they sow to these three activities each irrigation season in response to various market forces and water supply conditions. Irrigated winter pasture represents the activity with the largest area sown in the Murrumbidgee Valley. The decision as to what area to be committed to irrigated winter pasture is usually made in January and is a function of the amount of water (and land) available, with non-irrigated land generally becoming dryland pasture. This is a within-season decision and is for the most part independent of the preceding irrigation season.

The Murrumbidgee Valley is an extremely complex system and a number of simplifying assumptions have to be made to minimise computational difficulties. The general assumptions that are used in the study are as follows: (a) one decision maker for managing the reservoirs and a single decision maker for each region; (b) multiple irrigated and dryland crops; (c) two reservoirs; (d) no significant distribution system or on-farm storage; (e) tributary flows are included; (f) rainfall occurs mostly in winter; (g) deterministic demand for water with annual planting decision points (i.e. crop and water use decisions are made once per year); (h) certain supply of water within a season but stochastic across seasons; (i) irrigation products from the region are assumed to have perfectly elastic demands and constant prices; (j) no return flows; (k) no transferability of water between users; (l) constant water use technology; and (m) crop growing conditions are assumed constant across years.

The study has assumed January to be the annual planting decision point. This implies that irrigators have perfect knowledge of the announced allocation percentage at this time and base their cropping plans on the water available in this month. Although summer crops (notably rice) are planted in October, irrigators will rarely base their plans on the announced percentage allocation in this month as the announced percentages generally increase over the irrigation season[3]. This decision planting point also correlates with that of DWR for estimating the reliability of supply.

4.2 Regional linear programming models[4]

The four regional linear programming models were developed with the objective function to maximise regional net farm income. The MIA, MID and CIA models share a common specification structure, although there are considerable differences in resource constraints and model coefficients. Differences in irrigation technology are major determinants of yield variations in crops and pastures. The major difference is whether or not flood irrigated land has been landformed with laser controlled equipment. Therefore, land is classified on the basis of whether it is landformed or still in the original non-landformed contour bay layout. Also, dryland areas are distinguished from irrigable land. In the MIA, MID and CIA there is a maximum permissible limit on the area of rice that can be sown, known as the rice area restriction, which has been imposed to alleviate the environmental problems associated with rising watertables.

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[3] The hydrology simulation model indicated that, for the current allocation and supply reliability policy, when the October announced allocation was less than 120 per cent there was only one irrigation season over the 99 year period when the announced allocation percentage did not increase between October and January. Even when the simulation model was run for larger levels of irrigation development, there were only a few years when announced allocation percentages did not increase between October and January.

[4] A more detailed account of the specification of the models can be found in Jones (1991).

Other constraints apply to certain restrictions on some crops, annual water allocation, monthly channel supply capacities, and labour. In addition to the above restrictions, constraints also apply to crop selling pools, pasture supply pools, crop-pasture rotation ties, and fixed costs.

Crop enterprises are presented as rotational activities. This approach is used because it is a practical and flexible way of dealing with rotation plans in a single period linear programming model. In the Murrumbidgee Valley there is a wide range of rotational choices which involve the same crops. For instance, typical rice-wheat-pasture rotations can have up to three successive years of rice, which may be followed by up to two years of wheat, and/ or up to four years of irrigated winter pasture. Alternative rotations can have significant differences in their irrigation requirements and the levels of other inputs, as well as yield, and must be included in the specification for each rotation activity in the model.

Separate rotations have been specified for landformed and non-landformed areas, although for the most part the crop rotation plans remain the same but yield and input coefficients differ. Irrigated pasture follows a cropping sequence via pasture-rotation tie constraints. This means that a crop rotation will be followed by either two, three or four years irrigated winter pasture phase. There is also the possibility of dryland winter pasture being grown on non-irrigated areas. Hay can be made from irrigated winter pasture in spring and fed out in either summer or autumn. Livestock demands are represented by a number of sheep enterprise activities which draw their feed requirements from a seasonal feed pool. Crop selling activities apply to rice, soybeans, maize, sunflowers, wheat, barley, canola and vegetables. Labour requirements in excess of that provided by operator's labour can be obtained by hiring casual labour. Irrigation water is obtained by a water buying activity.

In the CIA, which is located on the southern side of the Murrumbidgee River, additional land constraints apply due to a greater diversity in the range of soil types. For environmental reasons, soil types in the CIA are classified as being either suitable, marginal or unsuitable for rice. In the former category, no restrictions apply to rice cropping. If land is marginal, farmers are only permitted to grow one crop of rice every four years on that area of land. If land is termed unsuitable then no rice production is permitted. This last group of soils has a lower clay base and is of a sandy nature which can lead to significant accessions of applied irrigation water to the groundwater system when water is ponded during rice production. This contributes to the phenomenon of rising watertables and the associated waterlogging and soil salinisation problems that ensue.

The private diverters model encompasses all irrigators who pump their irrigation requirements directly from the river and do not rely on public funded channel supply systems. The area involved is along the Murrumbidgee River from Burrinjuck Dam downstream to the confluence with the Murray River and includes what are known as the distributaries which break off from the main river. This region has a significant component of production which is dryland agriculture, with the irrigated areas representing a small proportion of the total area. Agricultural production along the river differs from the irrigation areas and districts in that it is principally pasture based, and until recently rice production did not occur[5]. Small areas of irrigated cropping do occur along the river but, as irrigated pasture is planted on over 80 per cent of irrigated land, pasture activities are primarily represented in the model.

For the purposes of this study the river has been divided into four zones. This is due to significant differences in farm sizes, licensed irrigation area as a proportion of total farm area, pumping capacity (the ability to draw water from the river per month), and pasture yields between the 'wetter' eastern portion of the Murrumbidgee Valley to the 'drier' western portion. Zone 1 is from Burrinjuck Dam to Narrandera, Zone 2 is from Narrandera to Hay, Zone 3 is from Hay to the Murray River and Zone 4 comprises the distributaries. Activities in each zone are primarily based on irrigated winter and

[5] Controls on the location of rice production have been marginally relaxed. Therefore, this is a crop which may be planted to some extent in the future along the river.

summer pasture, and small areas of winter cereals and summer crops.

4.3 Hydrology simulation model

The hydrology model used in this study was developed by the DWR to simulate the behaviour of the Murrumbidgee system and to assess the effect of various operational and licensing arrangements on the behaviour of the system. The "performance" of the Murrumbidgee system as simulated is judged mainly by the following parameters:

(a)Announced allocation percentage. The volume of water available for allocation to Murrumbidgee irrigations at a particular time is compared with the volume of licensed irrigation in the valley.

(b)Allocation reliability. Reliability of allocation is a measure of the chance of obtaining a stated allocation percentage. It is calculated as the percentage of years that the stated allocation is available over the period simulated.

The availability of streamflow data determines the period over which the simulations can be carried out. Flow data have been recorded on the Murrumbidgee system at Gundagai, Wagga Wagga, Narrandera, Hay and Balranald since the 1880s. The period of simulation that is used is from May 1890 to April 1989, comprising 99 irrigation seasons. The model uses a simulation time step of one month.

5. Derivation of irrigation development and supply reliability scenarios

As irrigation development increases throughout the Murrumbidgee Valley the reliability of supply will tend to decline. The effect of these lower reliabilities was studied by varying irrigation development from the current level (92 per cent usage of current licensed allocation) to 150 per cent development of current licensed allocation. The hydrology simulation model was used to provide annual announced allocation percentages for the 99 year period from 1891 to 1989. The data obtained related to irrigation development levels of 92 per cent, and from 100 to 150 per cent at 5 per cent increments. Irrigation development is accomplished by increasing the licensed allocation in the Murrumbidgee Valley, from a current level of 2,052,455 megalitres to 3,078,683 megalitres at a 150 per cent irrigation development level.

In determining the irrigation development/supply reliability scenarios, a number of assumptions were made. Foremost among these, as discussed in section 4.1, was that any further development in the Murrumbidgee Valley would occur along the river rather than in the irrigation areas and districts. Development along the river by private diverters is at private expense and there are few limitations on suitable land and ability to distribute water to irrigated lands. In addition, it is also considered that this irrigation development will occur in the western portion of the valley, that is from Narrandera to the Murray River. This is the area where most additional suitable land for extra flood irrigation lies.

As most holdings located along the river have some form of irrigation entitlement, it is assumed that existing farms will be the beneficiaries of increased allocations rather than water being made available to farms which currently have no irrigation. The study does, however, consider increases in overhead costs to existing farms expanding their irrigation areas. These costs include new or upgraded irrigation pumps, supply infrastructure and general maintenance.

The study assumes that "sleeper licenses"[6] will be activated so that all licensed allocations will be utilised. A base irrigation development scenario of 92 per cent usage of licensed allocations represents the current situation where usage, at 1,888,259 megalitres, is below the licensed allocation of 2,052,455 megalitres. This is primarily due to the existence of the sleeper licences. To calculate this scenario it is assumed that all sleeper licences occur along the river, thus licensed allocation values in the private diverters model are reduced to a level which results in a 92 per cent usage for the entire Murrumbidgee Valley. This assumption closely parallels reality. Efforts are being made by the

[6] The term"sleeper licenses" is used to describe licensed allocations which are held by individual landholders but which are rarely, if ever, utilised.

DWR to activate sleeper licenses through the introduction of permanent transferable water entitlements, changing water pricing structures, or the resumption of unused allocations.

6. Results

6.1 Supply reliability levels for different irrigation developments

The hydrology simulation model was solved for the different irrigation development scenarios to give the annual allocation for each year of the simulation period. From this data the supply reliabilities were calculated and these are presented in Table 1. This indicates that, at the base level of irrigation development, irrigators receive at least their entitlement 96 years in every 100. In most of these 96 years, irrigators would receive up to 120 per cent of their normal entitlement. As irrigation development is increased, the level of supply reliability in the Murrumbidgee Valley declines. For example, at 125 per cent irrigation development reliability is 73 per cent, and at 150 per cent development, reliability it is 57 per cent.

Reliability of supply does not describe the severity of the water shortages that may occur. For example, the irrigation development scenarios of 145 and 150 per cent have the same reliability of 57 per cent. This does not mean these development levels each give the same net income, it merely means that these scenarios result in the same number of years that at least normal entitlement is received. There is no description of the magnitude of the percentage of annual allocation, which will generally be lower for the larger development level. A measure termed the average allocation percentage, which is an average of actual announced allocation, better describes the availability of irrigation water. The results in Table 1 indicate that at the base level of development, the average annual allocation is 118 per cent, meaning that irrigators in the Murrumbidgee Valley receive on average 118 per cent of their annual allocation. As irrigation development increases, the average allocation declines. At 125 per cent irrigation development average allocation is 105 per cent, and at 150 per cent development average allocation is 95 per cent. This illustrates that, although there is a significant decline in supply reliability over this range, the average allocation of irrigation water that irrigators in the Murrumbidgee Valley annually receive remains reasonably high.

Table 1: Supply reliabilities at different irrigation development levels

Level of development (%)	Supply reliability (%)	Average allocation (%)
92	96	118
100	91	115
105	87	113
110	84	112
115	80	109
120	78	107
125	73	105
130	68	103
135	67	101
140	62	99
145	57	97
150	57	95

The above discussion demonstrates the need to consider the average allocation percentage along with supply reliability in any study such as the one being conducted. Different average allocations can have a similar supply reliability but vastly differing net income values.

6.2 Average annual net incomes and standard deviations for alternative allocation and supply reliability policies

The average annual net income and standard deviations for the total Murrumbidgee Valley and the four separate regions are presented in Tables 2 to 6 inclusive. This information illustrates that, although there is an overall increase in average regional net income for the total Murrumbidgee Valley and the private diverters region with a greater irrigation development, there are declines in average net incomes for the MIA, MID and CIA.

The results presented in Table 2 illustrate that for each irrigation development scenario greater than the base irrigation development scenario a greater average annual net income can be achieved, but at the expense of greater income variance. For a decision maker who prefers greater income regardless of variance, this would lead to a rejection on efficiency grounds of the current allocation and supply reliability policy in the Murrumbidgee Valley. However, for decision makers who are averse to high income variability, as measured by the standard deviation, it is quite possible that the current policy is acceptable. For the majority of irrigation farmers in the valley, any fall in supply reliability will result in significant reductions in their average net farm incomes.

This study does not specifically present an optimal supply reliability and allocation policy as this would involve a value judgement concerning society's trade-off preference for income and income variance. For instance, if society preferred the highest level of income achievable, regardless of variance, then the optimum policy would correspond to an irrigation development level of 115 per cent. On the other hand, if society's objective was to minimise revenue variance then the optimum policy would be at the base irrigation development scenario, or possibly less. The results do indicate that, depending on the trade-off preference, the optimum policy will most likely lie between the base irrigation development level and a development level of 115 per cent. This assumes that no externalities would arise from the introduction of an optimal policy. These effects would need to be valued if they were to occur.

Table 2: Average annual net income and standard deviation of the Murrumbidgee Valley

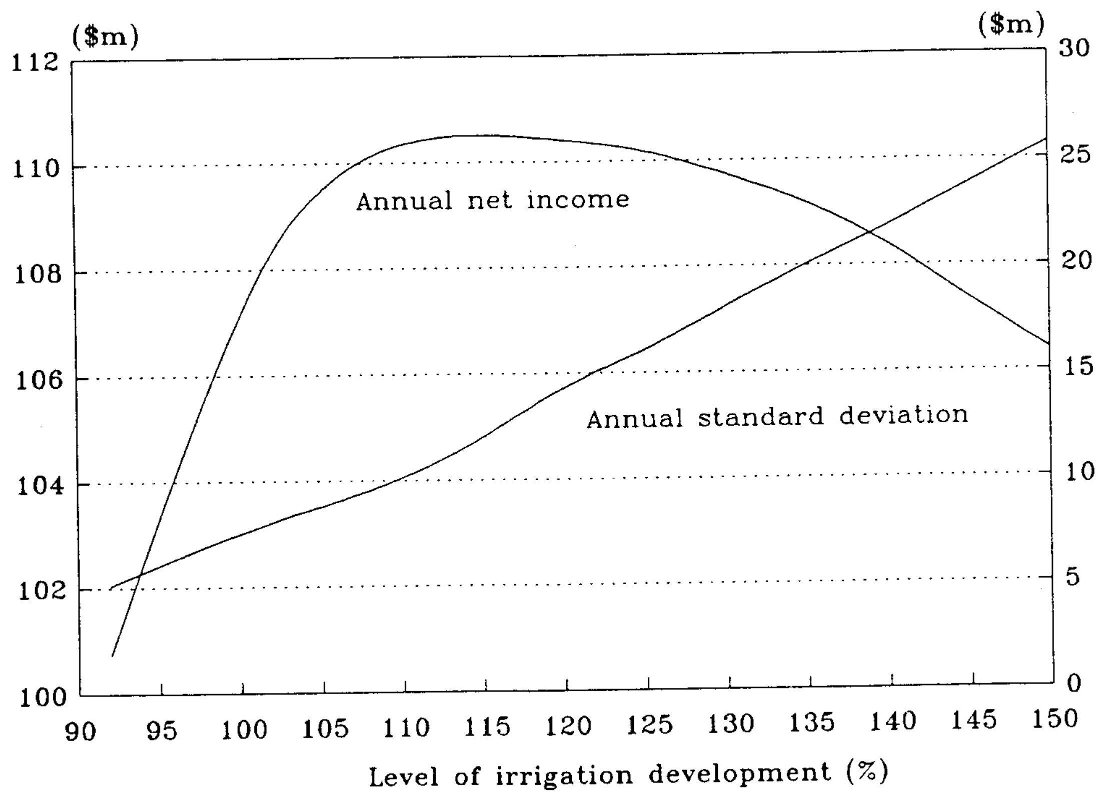
Level of development (%)	Annual net income ($m)	Annual standard deviation ($m)
92	100.73	5.08
100	107.70	7.62
105	109.70	8.76
110	110.44	10.00
115	110.55	11.90
120	110.41	14.49
125	110.24	15.97
130	109.75	18.12
135	109.23	20.08
140	108.47	21.77
145	107.35	23.83
150	106.41	25.78

The average annual net income and standard deviation which corresponds to each irrigation development scenario for the Murrumbidgee Valley is graphically presented in Figure 2. The shape of the curves in Figure 2 are consistent with Dudley's annual net revenue and total net revenue variance curves in Figure 1. The maximum point on the average annual net revenue curve corresponds with an irrigation development of 115 per cent and supply reliability of 80 per cent with the average annual net income being $110.55m. There is little difference in the average annual net income values for irrigation developments between 110 to 125 per cent. As both the standard deviation and average annual net income values are increasing over the range from the base irrigation development to 115 per cent development, any increase in irrigation development within this range will lie within Dudley's rational zone for irrigation, that is between the points *OC* and *OD* in Figure 1. The annual standard deviation results represent the total net revenue variance curve in Figure 1, thus they take into account both irrigation and dryland net revenue variance.

Increasing the level of irrigation development to 115 per cent would result in a 307,868 megalitre rise in licensed allocation, from 2,052,455 megalitres to 2,360,323 megalitres in the Murrumbidgee Valley. This represents the maximum volume of extra irrigation water that should be allocated in the Murrumbidgee Valley. Water usage, however, increases by 472,064 megalitres from the 1,888,259 megalitre usage at the base irrigation development scenario. Associated with the larger allocation is an increase in the irrigated area of the Murrumbidgee Valley, from the current area of 390,018 hectares to 441,329 hectares.

Based on the modelling assumptions made, average annual net returns in the Murrumbidgee Valley could be improved by approximately $10m by moving to an irrigation development of 115 per cent from the base scenario. This represents a 10 per cent increase in average annual net returns. However, there would be a substantial increase in revenue variance as measured by the annual standard deviation. To illustrate the variability of returns, Figures 3 and 4 indicate the annual net

Figure 2: Average annual net income and annual standard deviation for the Murrumbidgee Valley



revenues over the 99 year simulation period for the Murrumbidgee Valley for the base and 115 per cent irrigation developments. These figures demonstrate the increasing variability of annual returns as irrigation development increases.

Distributive impacts would be associated with an increased irrigation development, and reduced supply reliability, as there would be declines in average annual net returns in the MIA, MID and CIA. At an irrigation development level of 115 per cent, average annual net income in the MIA falls by $1.66m from $18.57m for the base scenario (Table 3), representing a 9 per cent decline, while annual standard deviation increases by $2.48m from $1.44m. Net returns in the MID are also reduced by 9 per cent for the same level of irrigation development, declining by $0.74m from $8.42m, while annual standard deviation increases by $1.14m from $0.63m (Table 4). Average annual net income declines by 23 per cent in the CIA, falling by $0.63m from $2.73m, while annual standard deviation rises by $0.93m from $0.55m (Table 5). Although the magnitude of the values for the CIA are not large in comparison to the Murrumbidgee Valley total in absolute terms, the percentage change is significant and the impact upon individual irrigators would be substantial.

Offsetting the declines in net returns in these regions is an 18 per cent improvement in total average annual net income for the private diverters region, increasing by $12.83m from $71.02m at the base scenario (Table 6). Coinciding with this, annual standard deviation increases by $2.44m from $2.45m. Average annual net returns continue to increase up to 140 per cent irrigation development (62 per cent supply reliability) when annual net income is $85.78m.

Farms holding irrigation licences along the Murrumbidgee River in the private diverters region

Figure 3: Annual net income for Murrumbidgee Valley at base irrigation development - 1891 to 1989

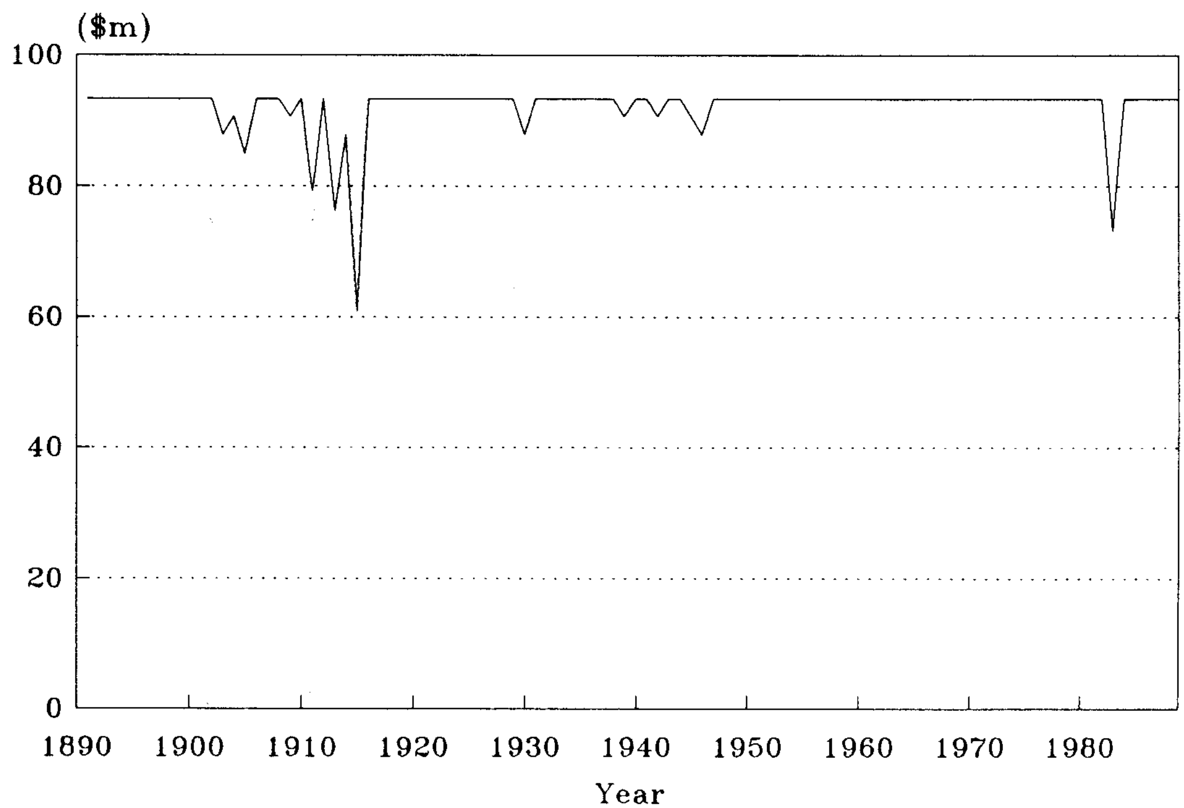
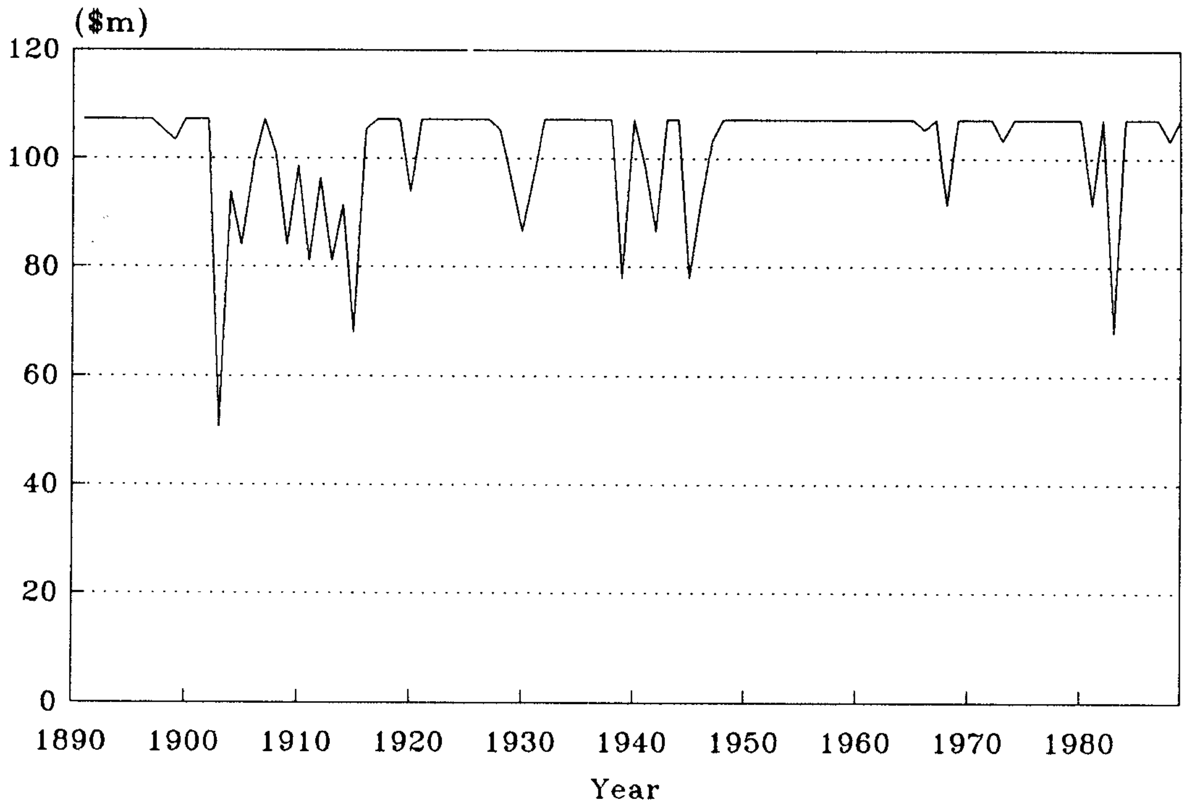


Figure 4: Annual net income for Murrumbidgee Valley at 115 per cent irrigation development - 1891 to 1989



have very large areas of dryland pasture production which account for a large portion of the average annual net incomes. It is for this reason that, for each level of irrigation development, these values are significantly higher for this region than the MIA, MID and CIA, which are typified by small farms with virtually no dryland areas. The high returns to water in the private diverters region, as indicated by the increased average annual net income as irrigation development expands, is due to large increases in the areas of irrigated pasture which is used to supplement dryland grazing activities. This implies that, with water rather than land being a limiting constraint to production, there would be the potential for irrigation water via a permanent transferable water entitlement scheme to gravitate from the Areas and Districts to this region.

It should be noted that, although there is an increase in total average annual net income for the private diverters region up to a 140 per cent irrigation development level, there are likely to be declines in average annual incomes for some individual farms within this region. This is because irrigation development has been assumed to remain static in Zones 1 and 4, with the extra development occuring in Zones 2 and 3 as discussed in section 5. Therefore, not only will there be distributive impacts between regions, but these impacts will occur within regions.

7. Summary and conclusions

The quantification of the average annual net income and standard deviation for a variety of irrigation development scenarios in the Murrumbidgee Valley was undertaken and reported above. The study did not specifically present an optimal water allocation and reliability policy as this would involve a value judgement regarding society's trade-off preference for income and income variance. A

Table 3: Average annual net income and standard deviation of the Murrumbidgee Irrigation Areas

Level of development (%)	Annual net income ($m)	Annual standard deviation ($m)
92	18.57	1.44
100	18.04	2.34
105	17.71	2.87
110	17.37	3.39
115	16.91	3.92
120	16.48	4.42
125	16.03	4.72
130	15.57	5.05
135	15.15	5.37
140	14.72	5.66
145	14.29	5.95
150	13.91	6.17

range of policies were presented, illustrating that as irrigation development expanded, annual net income increased with a corresponding rise in annual standard deviation. A maximum annual net income

Table 4: Average annual net income and standard deviation of the Murrumbidgee Irrigation Districts

Level of development (%)	Annual net income ($m)	Annual standard deviation ($m)
92	8.42	0.63
100	8.19	1.03
105	8.04	1.28
110	7.88	1.53
115	7.68	1.77
120	7.49	2.00
125	7.29	2.13
130	7.08	2.29
135	6.89	2.44
140	6.69	2.58
145	6.48	2.72
150	6.31	2.82

Table 5: Average annual net income and standard deviation of Coleambally Irrigation Area

Level of development (%)	Annual net income ($m)	Annual standard deviation ($m)
92	2.73	0.55
100	2.52	0.90
105	2.40	1.09
110	2.27	1.29
115	2.10	1.48
120	1.93	1.66
125	1.76	1.77
130	1.59	1.90
135	1.43	2.03
140	1.27	2.14
145	1.11	2.25
150	0.97	2.33

coincided with an irrigation development level of 115 per cent. If society is indifferent toward

Table 6: Average annual net income and standard deviation of private diverters

Level of development (%)	Annual net income ($m)	Annual standard deviation ($m)
92	71.02	2.45
100	78.95	3.38
105	81.55	3.56
110	82.91	3.88
115	83.85	4.89
120	84.52	6.64
125	85.16	7.53
130	85.52	9.07
135	85.76	10.41
140	85.78	11.50
145	85.47	13.01
150	85.22	14.55

income variance then the current allocation and supply reliability policy should be rejected as all irrigation development scenarios greater than the base allocation scenario gave a higher average annual net income. If society is averse to high income variance levels then it is not clear that the current high reliability policy should be rejected. However, depending upon the trade-off preference, the optimal policy should be between the base and 115 per cent level of irrigation development.

Distribution impacts were identified to occur due to the adoption of alternative allocation and supply reliability policies. Average annual net returns in the MIA and MID would each decline by 9 per cent, CIA net returns would fall by 23 per cent, while the private diverters region would benefit from an 18 per cent improvement in average annual net income if irrigation development increased to 115 per cent.

There are a number of conclusions that can be drawn from this analysis. First, economic efficiency can be improved by increasing the level of irrigation development in the Murrumbidgee Valley if society prefers greater income regardless of any increase in revenue variance. This results in a greater amount of water that is annually allocated and a lower level of reliability of supply. By allocating an extra 307,868 megalitres of water annually, activating sleeper licenses and operating at a supply reliability of 80 per cent, average annual net returns in the Murrumbidgee Valley can be improved by $10m, or 10 per cent.

Second, any increase in irrigation development which results in a lower supply reliability will have distributional implications. The average annual net incomes of existing irrigators in the MIA, MID and CIA will decline. This will make the introduction of supply management reforms difficult as they will be met with considerable resistance from existing irrigators in these areas. The introduction of a package of reform which includes demand as well as supply management measures, particularly permanent transferable water entitlement markets, is highly desirable to provide the flexibility for irrigators to attain the level of allocation and reliability most suited to their individual needs.

Finally, there will be environmental and third-party implications from a change in allocation and supply reliability policy in the Murrumbidgee Valley. There may be the potential for a number of beneficial impacts, such as a reduction in the economic costs of salinity and waterlogging in the Areas and Districts due to a reduction in water usage and possible incentives to adopt improved irrigation technologies. However, there may be negative impacts. These include increased drainage pressures if there is a large scale adoption of laser controlled landforming, and the broader environmental implications on the quantity and quality of flows in the Murray River if there is a substantial reduction in dilution flows from the Murrumbidgee River due to greater irrigation commitments.

The study has not considered the use of increased licensed allocations in the Murrumbidgee Valley for purposes other than irrigated agriculture. The possibility of allocating the additional supplies of water to alternative purposes, such as the environment, may have an impact upon these results and would be an important extension to this study. Unfortunately, there is a lack of information pertaining to the economic value of use of water for environmental purposes and greater research efforts are required to remedy this information void before a more comprehensive analysis, which includes all possible uses of water, can be undertaken.

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