Author: M. E. Quereshi, S. R. Harrison, M. K. Wegener and K. L. Bristow
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Author Address:
kbristow@csu.edu.au

IRRIGATION WATER PRICING AND FARM PROFITABILITY IN THE BURDEKIN DELTA SUGARCANE AREA

M.E. Qureshi[1], S.R.Harrison[2], M.K Wegener[1,3] and K.L.Bristow[1,4]
[1]CRC Sustainable Sugar Production, James Cook University, Australia
[2]School of Economics, The University of Queensland, Australia
[3]School of Natural and Rural Systems Management, The University of Queensland, Australia
[4]CSIRO Land and Water, Townsville Qld 4814

Abstract

The Burdekin delta in north Queensland is one of the most important areas for irrigated sugarcane production in Australia. Conjunctive use of groundwater and surface water is commonly practiced in the area and cane yields are amongst the highest in the nation. Some soils are highly permeable and given current furrow irrigation technology can use high amounts of water, so costs could rise considerably if higher water charges were imposed. This paper describes a farm level mathematical programming model developed to determine optimal levels of irrigation water applied to a farm comprised of the average proportions of major soil types. A biophysical simulation model has been used to determine cane productivity for these various soils at various levels of irrigation. Average amounts of irrigation water applied and yields over a 20-year period are used as input to an optimisation model which estimates cane profitability per hectare for each soil type under current and alternative water pricing arrangements. Optimal farm plans are compared between two Water Board areas with differing water charge structures. The optimisation model estimates the profit-maximizing amounts of irrigation for the various soil types. Sensitivity analysis has been performed with respect to parameters affecting farm profitability, including cane price and proportion of land containing each soil type. Optimal irrigation levels across soil types are determined for various water pricing policies. The optimal water application levels for a farm in the South Burdekin Water Board (SBWB) area are higher than those for the North Burdekin Water Board (NBWB) area. The optimal water levels for the two farms under a volumetric water charging option are lower due to higher water costs. The profitability of cane on low permeability soil is higher than on medium and high permeability soil types because of better water holding properties. Results indicate that profitability of the SBWB farm is higher than the NBWB farm due to the relatively greater use of less expensive groundwater on the SBWB farm compared to the NBWB farm.

Keywords: Irrigation, productivity, simulation, optimisation, water policy

Introduction

Water is becoming an increasingly scarce resource and therefore constraining agricultural development in many regions and countries of the world. In the past, new physical systems have been built to harness additional water resources when demand for water exceeded supply. However, with increasing demand by users in agriculture as well as from other industries, and increasing concern within the general community about potentially harmful externalities of irrigation, emphasis is now being placed on improving the performance of existing irrigation systems. In Australia, efficient and sustainable management of water resources is increasingly becoming a policy objective (Thomas, 1999).

There are several factors to be considered in irrigation management to improve productivity and reduce costs. One of the key decisions is how much water should be allocated to a particular crop relative to other crops. This decision needs to be based on the quality and availability of water resources, reliability of water supply, physiological requirements of the crop, and the expected value of crop output.

For a canegrower, many possible strategies can be followed when deciding the optimal level of irrigation water to apply. A frequently followed strategy is to apply water to an individual block of cane at a level that achieves maximum crop yield. This approach may be used when there is no restriction on irrigation water supplies and little extra cost involved in the application of additional water. However, when water supplies are limited, or when additional marginal quantities of water incur a rising cost, it is obviously better to provide the optimal or efficient level of irrigation water across various crops on the farm, in order to achieve a higher overall level of farm profitability. The efficient allocation of water must strike a balance between competing crops on the farm and crops on different soil types. This requires an economic modelling approach which can determine the optimal allocation of water for various crops and soil types.

This paper briefly describes an optimisation model used to estimate private (farmer) profitability of irrigated sugarcane on farms with multiple soil types. This model is designed to aid farm managers in decision making to achieve optimal irrigation levels for farms with various soil types in one of the major canegrowing areas in Australia. The paper then examines the impact on farm profitability and optimal level of irrigation due to changes in water charges, pricing structures and sugar price for a representative sugarcane farms in both the North and South Burdekin Water Board Areas of the Burdekin delta. In the following section, the theoretical concepts underpinning the determination of economically optimal irrigation rates are discussed. Issues pertaining to the case study area and need for effective irrigation management are then presented. The analytical framework used in the current study is described and the results discussed.

Economically optimal water use: theoretical background

Economic efficiency refers to the combination of inputs that achieves individual or social objectives to the greatest possible extent in relation to individual farms and to society. In the case of a single variable input, economic efficiency relies on the location of the production function on which the farm is operating. The most profitable point of operation is obtained either by determining the most profitable amount of input or the most profitable level of output. Either method results ultimately in the same optimal level of the variable input because the production function relates input to output in a unique manner. The maximum profit does not occur where physical output is at a maximum if there is a price attached to the input. This is because a stage of diminishing marginal product from a single variable input (such as irrigation water) usually exists and, beyond the point of maximum profit, the added units of input cost more than they are able to earn. Thus the quest for maximum yields is not always an economically sensible goal, and at times can also be less than optimal environmentally. Using inputs beyond the point of greatest efficiency is not consistent with profit maximisation unless all inputs into the production process are free (Doll and Orazem, 1984). This principle applies when examining both private and social efficiency.

Farm production processes are considered efficient when production inputs are allocated optimally. However, if the expenditure on an input (irrigation water) is low compared to other costs of production, then the optimal quantity will approximate that leading to maximum crop yield. This situation is particularly likely to occur when inputs are provided at less than their full cost, possibly because they are underpriced or because an important cost element, such as the impact on the environment, has been overlooked. Optimal use of an input occurs when the marginal value product (MVP) equals the cost per unit of the input (P_X).[1] If MVP is lower than P_X, the resource is over-utilised and reducing the quantity used at the current price will increase the MVP towards optimality. On the other hand, if MVP is greater than P_X, the resource is over-utilised and using more of it will not bring additional gains to the grower.

For farmer decision making, the price of the input P_X includes only private costs, not social costs. In the past, many irrigation schemes operated on the basis of recovering operating costs only. Increasingly, prices for irrigation water are being increased to include two additional components: charges for the use of the capital works involved in the delivery of irrigation water and some payment to the community for the use of the environmental resource. In other words, some of the externalities involved in the use of irrigation water are being borne by irrigators. Thus farmers who use water delivered by public schemes are being asked to pay more for the input as part of a strategy to achieve greater efficiency and more equity in the use of resources.

In situations where there are a number of crops, efficiency dictates that the marginal net benefit (marginal revenue of product less marginal cost of input) be equalized for all crops. If marginal net benefits are not equal, it is always possible to increase aggregate benefits by transferring water from those crops with low marginal net benefits to those with higher marginal net benefits provided there is enough flexibility to allow water reallocation. The benefits given up by those crops losing water are less than those gained through crops receiving additional water. This procedure results in allocative efficiency (Samuelson and Nordhaus, 1987). At this stage, water is efficiently allocated and no other outcome can improve the welfare of the water user.

If a farm or region has various soil types, then similar economic principles apply in the allocation of water to each soil type, and maximisation of farm profit is achieved only if there is an optimal level of irrigation on each soil type and marginal productivity of water use is the same across all soil types. Efficiency dictates that

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[1] The marginal value product of applied water is a product of output price, marginal product of effective water, and irrigation efficiency (Boggess et al., 1993).

the marginal net benefit be equalized for all sites or soil types for each crop. When there is a single crop dominant in a region (due to either economic or agronomic conditions), the optimal level of water application is still achieved when the cost of one additional unit of water is equal to the additional revenue it generates.

In situations such as the Burdekin delta where only one crop, sugarcane, is predominantly grown, there may currently be no competition for the irrigation water from other crops or industries, but the threat of competition from new non-agricultural users has to be considered. If water is an underpriced resource in the region, it will ultimately attract new users (other crops or non-agricultural activities depending on water productivity) into the area and it is better for the farmers concerned to be making the necessary adjustments well ahead of that eventuality.

Mathematical models in irrigation planning and water pricing policies

Mathematical programming models can be used to determine optimal activity and resource input levels. These models are quantitative in the sense that they indicate, for example, the number of units of each commodity or output to be produced and number of units of each input to be used if a stated goal such as profit maximisation is to be attained. Linear programming (LP) has been used extensively in the analysis of water resource systems and irrigation planning. Some examples are now presented.

Kheper and Chaturvedi (1982) applied an LP model to make decisions about groundwater management options in conjunction with optimal cropping pattern and water production functions. Panda and Kheper (1985) used deterministic LP and chance-constrained LP to maximise net return from irrigation planning. Paudyal and Gupta (1990) solved the complex problem of irrigation management in a large heterogeneous river basin by using a multilevel optimisation technique. They determined the optimal cropping patterns in various sub-areas of the basin, the optimal design capacities of irrigation facilities, including surface and groundwater resources, and the optimal water allocation policies for conjunctive use. Mainuddin et al. (1997) used an LP model to determine the cropping pattern to ensure optimal utilisation of available land and water resources in a groundwater irrigation project.

Mathematical programming models have also been used to determine demand for water and water pricing policies and impact of these policies on water demand. Chewings and Pascoe (1988) used LP to simulate water use in the Murray Valley in New South Wales, Australia. They investigated the major consequences of various water pricing policies, subject to resource availability, costs and commodity prices as well as deriving demand functions for water in the valley, by parametising water price changes over a specified range. Tisdell (1996) used an LP model to estimate demand functions for water in Border Rivers region of Queensland by varying water charges. Ulibarri et al. (1998) estimated the change in farm profitability from imposing full-cost federal water and power rates using an LP model in California. Varela-Ortega et al. (1998) used a multi-period mathematical programming model to analyse the effect of various water pricing policies on water demand, farmers' incomes and the revenue collected by a government agency in Spain. Amir and Fisher (1999) used an optimising model to analyse production under various water quantities, qualities and pricing policies, and determined water demand curves for various districts in Israel. Berbel and Gomez-Limon (2000) applied an LP model to three farms in different irrigation units and examined the impact of water price policy on farm income and on regional employment in Spain. They also determined water demand curves that reflected farmers' adaptation to rising costs of production inputs.

Case Study: Burdekin delta irrigation area

The Burdekin River delta is located approximately 90 km south of Townsville on the northeast coast of Australia, close to wetlands, waterways, estuaries and the Great Barrier Reef. It covers an area of about 850 km^2, and together with the Haughton River – Barratta Creek system, is one of the largest alluvial aquifer systems in Australia. The area has a tropical climate and seasonal rainfall (two thirds of the annual rainfall ranging between 250 mm and 2500 mm)with an average of about 1000 mm, with most falling during January to March. Evaporation rates vary between 10 mm/day in November and 2.8 mm/day in June. The delta is predominantly used for sugarcane production, with some smaller areas under tropical fruits and vegetables. There are small areas where groundwater or soil quality is not suitable for the sugarcane crop or horticulture, and these are used for cattle grazing. The delta is one of the few areas in Queensland where cane is grown under full irrigation and conjunctive use of groundwater and surface water is common practice [2]. The North and South Burdekin Water Boards (NBWB and SBWB) were established in 1965 and 1966 respectively, to replenish and manage the underground aquifers. Artificial recharge is still practised in the delta, although the Water Boards (particularly the NBWB) are promoting a practice of more efficient water use requiring less artificial recharge.

Sugarcane is the dominant crop in the delta with 21,800 ha planted in the NBWB area and 13,344 ha of cane in the SBWB area in 2001, and with only 1,500 and 84 hectares, respectively, under other crops (NBWB, 1998; SBWB, 1999). One way to achieve higher efficiency in water use is to ensure that the amount applied to cane is matched to soil types and crop demand. More water-efficient practices will reduce pumping costs for growers and increase farm profitability as well as reducing the potential risk of leaching nutrients and pesticides into the aquifer. Therefore, it is important to design and implement practices which ensure the long-term viability of irrigated agriculture in the area.

Analytical framework

The integrated approach applied in this analysis includes using a biophysical simulation model to predict crop yields of sugarcane, linked to a linear programming model to determine the levels of irrigation for various soil types which maximise farm profitability for a representative cane farm in the study area. A detailed description of the analytical framework and its components is presented in this section.

Biophysical models to determine crop yield
For a comprehensive economic analysis, biophysical information such as crop yield is necessary. The APSIM cropping systems model (McCown et al. 1996) has been used to obtain these data by linking a sugar crop module, a soil water module, a soil nitrogen module and a surface residue module, as described by Probert et al. (1997). The model 'APSIM-Sugarcane' was configured to simulate continuous cropping over a 20-year period from 1975 to 1995 with a cycle consisting of one plant crop followed by three ratoon crops. A series of crop simulations have been performed to estimate response to applied irrigation water for a range of soil types, water allocation levels and application efficiencies, under the widely used furrow irrigation system. The water inputs and yields obtained from the 20-year simulation runs have been averaged. Further details of this analysis are provided by Qureshi et al. (2001).

A selection of irrigation options were chosen for the investigation based on combinations of soil types, water quantities (0 to 35 ML/ha in 1 ML/ha increments) and above-ground application efficiencies of 30% to 60% for three soil types, namely clay, silt and sand. The three soil types were selected to represent profiles with sharply contrasting levels of plant-extractable soil water (representative of low, medium and highly permeable soil types in the study area).

The long-term climate files for the study area from 1975 to 1995, consisting of daily rainfall, minimum and maximum temperature and solar radiation data, were used as inputs for the simulation analyses. These files are comprised of a combination of recorded weather station data and data from generated historical meteorological surfaces, obtained from the Bureau of Meteorology and the Queensland Centre for Climate Applications. Simulated yields were about 20% higher than the average sugar yield in the region because the model does not take into account losses associated with pests, diseases, weed competition and impact of waterlogging or unusual climatic events, and yields are based on uniform soil characteristics. Therefore, the yields for the various irrigation levels have been reduced by 20% for each of the three soil types. Average water inputs and yields simulated over the 20 years have been used in the economic analysis.

Burdekin delta irrigated crop programming model
A linear programming model has been developed using GAMS software (General Algebraic Modelling System, Brooke et al., 1998) to represent sugarcane farms in the delta area to analyse responses to changes in water prices and other management options in both the North and South Burdekin Water Board areas. The aim of the analysis for which the model has been developed was to determine optimal levels of irrigation for major soil types in the delta. The model can estimate after-tax annual net revenue of cane per hectare for each soil type under the current water-pricing scheme as well as under alternative pricing policies.

[2] Conjunctive use means using a combination of stored surface water and groundwater for irrigation

It is assumed that the farmers are risk neutral and their objective is maximisation of long-term profit from their activities. For the analysis (to maximise farm profit), the optimal levels of irrigation are determined for each soil type, amount of land resources allocated to crop type (plant cane and ratoons only), water source and irrigation level (which can vary from 0-35 ML/ha). Based on recent estimates (Arunakumaren *et al*., 2000), the proportions of the three soil types in the study area have been taken as low permeability 33%, medium permeability 56%, and high permeability 11%. Aggregate net revenue is calculated by deducting total costs from total revenue while after-tax net revenue is estimated by deducting tax payable from aggregate net revenue.

To analyse the impact of water charges, and changes in the proportion of water from different sources, it is convenient to express the LP objective function as the difference between total net crop returns and irrigation related production costs including other production costs and fixed cost. Cane production is assumed to be the sole income generating activity and the net revenue function includes a single income variable. Total revenue from each soil type and irrigation water level, represents income from selling cane to the local mill and is calculated using the standard Australian sugar industry price formula. In the model, costs are divided into three components: irrigation-related costs; other production costs such as fertiliser, harvesting, maintenance and other variable production costs; and fixed costs. Irrigation-related costs are obtained by adding irrigation system operating costs, electricity costs of pumping ground and surface water, groundwater costs and surface water costs.

There are differences in the structure of groundwater charges between the two water management authorities. Also, different proportions of groundwater and surface water are used in each jurisdiction, due to differences in quality of groundwater and need to recharge the aquifer. In the NBWB area, the proportions of groundwater and surface water available are 40% and 60%, while in the SBWB, these proportions are 70% and 30% respectively. The model distinguishes between the cost of surface water and cost of groundwater obtained from private wells. Further, the model takes account of a two-part pricing structure for surface water with low charges up to a threshold value and higher charges beyond the threshold. There are also differences between the two board areas in the threshold volume of surface water that is charged the low-rate. To calculate the charges for the surface water used, the volume of surface water up to and above the threshold is estimated, and multiplied by the appropriate charges. Further, the model takes into account the Australian standard progressive taxation system. Tax payable is estimated on the basis of net taxable income by considering marginal tax rates and the limits to the income brackets. The constraints in the model reflect the land area, amount of water, and labour and tractor hours available for the cane production systems under consideration.

Data acquisition procedure and sources

Information on technical and economic systems for the farms in the study area has been obtained from published literature, various government departments and organizations, Water Boards, farmers and their organisations, as well as from various irrigation and other business firms. Information from the various sources was cross-checked through informal discussion with local farmers and representatives of the various organisations.

Average yields from each soil type and for each irrigation system were generated by the APSIM model and have been used in the economic analysis. Sugar production cost data were obtained from a survey report compiled by the local Bureau of Sugar Experiment Stations office (Small, 2000) and from the local office of CANEGROWERS, with fixed costs estimated by the Australian Bureau of Agricultural and Resource Economics Farm Survey (ABARE, 1996). The information about permanent (family) labour hours used and labour costs were collected from growers and from the office of their association. Sugar content data for the past 10 years were obtained from the local sugar mill and an average was used in calculating crop returns. Similarly, the average pool price of sugar in Queensland was used and the price paid to the grower was estimated by using the standard sugar price formula. Water charges under the structured threshold payment system were obtained from material published by the Water Boards. Electricity charges were estimated on the basis of local electricity tariffs for the pumping of both groundwater and surface water. Detail of the parameters used in the analysis is given by Qureshi et al. (2002).

Results and discussion

A simulation experiment was performed using water charges for both the NBWB and SBWB areas along with a volumetric water charging policy option. The optimal water application levels for three soil types of

NBWB and SBWB area representative farms as well as of the volumetric water charging option are presented in Table 1. The optimal water application levels for a farm with three soil types in the SBWB area are higher than those for the NBWB area. The higher optimal levels are due to the relatively greater use of less expensive groundwater on the SBWB farms compared to the NBWB farms. The optimal water levels for both farms under the volumetric water charging option are lower due to higher water costs.

Table 1: Optimal water use level for three soil types for the NBWB and SBWB areas and the volumetric water charge option (ML/ha)

Soil type	NBWB	SBWB	Volumetric water charge option
Low permeability	23	27	22
Medium permeability	28	31	26
High permeability	35	35	35

Estimated net revenues (before-tax) per hectare for cane production on three soil types for the representative farms are reported in Table 2. These figures indicate that profitability of cane on low permeability soil is higher than on medium and high permeability soils. The profitability of each soil type is also higher for the SBWB farm than the NBWB farm, and much lower for the volumetric water charge option.

Table 2: Net revenue of cane growing from three soil types for the NBWB and SBWB areas and the volumetric water charge option

Soil type profitability	NBWB	SBWB	Volumetric water charge option
Low permeability ($/ha)	1816	1918	1235
Medium permeability ($/ha)	1612	1765	903
High permeability ($/ha)	1237	1425	356

Optimal after-tax revenues are presented in Table 3. The SBWB area farm has higher gross profit before and after tax than the NBWB area farm because of the higher proportion of less expensive groundwater used. The volumetric water charge option results in lower after-tax revenue due to relatively high water charges based on volume rather than charges based on area of production.

TABLE 3: Net revenue before and after tax for the NBWB and SBWB areas and the volumetric water charge option

Net revenue	NBWB	SBWB	Volumetric water charge option
Net revenue before tax ($/farm)	78630	85336	45714
Net revenue after tax ($/farm)	54294	57848	36848

The model has also been run to determine the optimal level of irrigation under a pricing schedule that involved increasing water charges. Here, only surface water costs have been increased to examine the impact on the optimal level of irrigation for three soil types in the SBWB area only because the groundwater charges are based on area of production and have no relation to the optimal level of irrigation. The optimal level of irrigation and after-tax income was determined for each soil type when water charges were increased in $10 increments (see Figure 1).

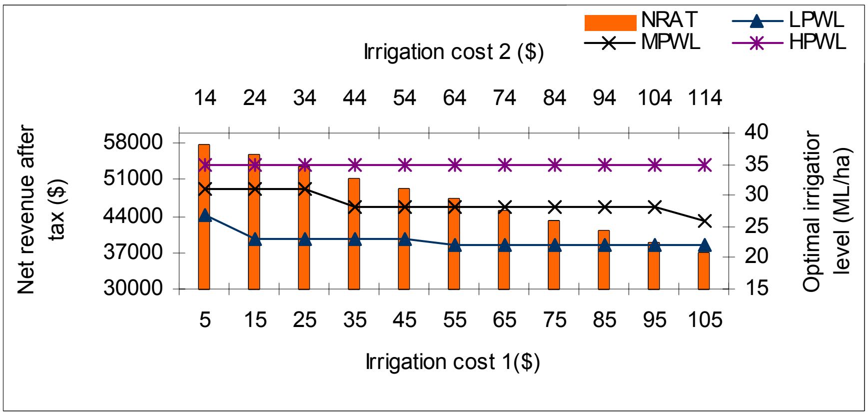

Figure 1: Surface water charges and their impact on optimal level of irrigation and farm profitability; NRAT is net revenue after tax; LPWL, MPWL and HPWL are optimum water levels for low, medium and high permeability

soils, respectively, Irrigation cost 1 is low surface water charge up to the surface water threshold while Irrigation cost 2 is high surface water charges above the surface water threshold.

The optimal level of irrigation for low permeability soils reduces from 27 to 23 ML/ha when there is only a $10 increase, then this level remains constant until the water charges are $45.40 and 53.67, respectively. This level of irrigation remains the same even when the low and high water charges are further increased to $95.40 and $103.67. For the medium permeability soil, the optimal water quantity changes from 31 to 28 ML/ha when the low and high water charges rise to $35.40 and $43.67, respectively, after which the quantities remain constant. The optimal water level for highly permeable soil type does not change with any price increase, indicating a highly inelastic demand for irrigation water in response to price changes. It is to be noted that for the SBWB area farm, the available proportion of surface water is only 30%. Therefore, the impact of any increase in surface water charges is not great due to its low contribution to total costs, although there is a sharp drop in after-tax farm income, from $57848 to $37011.

Conclusions and policy recommendations

The integrated approach developed in this paper to determine farm profitability from growing cane on farms in the Burdekin delta area with various soil types, captures both economic and biophysical relationships applying on an irrigated sugarcane farm in the area. The model estimates optimal levels of irrigation for various soil types, quantity of irrigation water used and crop yield, and determines the economically optimal level of water use taking into account input cost and output price. The model also estimates pre-tax as well as post-tax farm income.

The optimal water application levels for a representative farm in the SBWB area are higher than those for the NBWB area. The higher optimal levels are due to the relatively greater use of less expensive groundwater on the SBWB farms compared to the NBWB farms. The optimal water levels for both farms under the volumetric water charging option are lower due to higher water costs. The profitability of cane on low permeability soil is higher than on medium and high permeability soils. The profitability for the SBWB area farm is also higher than the NBWB area farm, and much lower for the volumetric water charge option.

The impact of changes in surface water charges on the optimal level of irrigation is minimal for low and medium permeability soils and has no impact on highly permeable soils. This is due to the low cost of additional surface water and the relatively high revenue obtained from its use. In addition, surface water contributes only a minor share of the total irrigation water applied (30%). The major source of irrigation is groundwater and the charges for it are based on area in production. Therefore, these charges have no impact on optimal irrigation level and thus no bearing on efficiency although they do have an impact on overall farm profitability.

The model could be used to provide useful information to farmers about the likely returns from growing cane on each soil type, and ultimately on overall farm profitability. It indicates that lower overall farm profits will be achieved if water prices are increased, even when the amounts applied change to reflect the economically optimal level. That suggests that farmers may have to change to water-saving methods of irrigation to maintain farm profits in the face of rising water charges. Sensitivity analysis with respect to surface water charges has proved useful for understanding the consequences of prospective policy changes. This approach can also be used to examine other farm management options that affect crop yield or sugar price, often by changing appropriate coefficients in the basic model. The proportion of ground and surface water or the proportion of soil types can be altered to suit the problem under investigation. The model can be easily adapted to analyse the impact of farm size, since the costs and revenues being used in the model are based on area estimates. The model can be readily adapted to allow for individual circumstances (e.g. differences in parameter levels due to differences in efficiency levels between growers) and therefore presents an efficient tool for developing farm management advice. At a policy level, the modelling framework provides a useful means for examining various scenarios and testing policy options that affect either input costs or output prices in sugarcane production. It is to be noted that this study has focussed on optimising water in a nutrient non-limiting environment without any restriction on the quantity of fertiliser use. The analysis has not included potential environmental issues (such as groundwater contamination due to nutrient leaching). Additional work is needed to account for externalities and optimise both water and nutrient management so that potential offsite impacts are minimised.

References

ABARE (1996) *Queensland Sugar Cane Industry 1993-94 to 1995-96: A Report Prepared for the Sugar Research and Development Corporation*, Australian Bureau of Agricultural and Resource Economics, Canberra.

Amir, I. and Fisher, F.M. (1999) Analysing agricultural demand for water with an optimising model, Agricultural Systems, 61(1): 45-56.

Arunakumaren, N.J., McMahon, G.A. and Bajracharya, K. (2000) *Water Management in the Lower Burdekin: Groundwater Model Conceptualisation,* Water Assessment and Planning, Resource Science and Knowledge, Queensland Department of Natural Resources, Brisbane.

Berbel, J. and Gomez-Limon, J.A. (2000) The impact of water-pricing policy in Spain: an analysis of three irrigated areas, Agricultural Water Management, 43(1): 219-238.

Boggess, W., Lacewell, R., and Zilberman, D. (1993) Economics of water use in agriculture, In: Carlson, G.A., Zilberman, D. and Miranowski, J.A. eds, Agricultural and Environmental Resource Economics, Oxford University Press, pp. 319-392.

Brooke, A., Kendrick, D., Meeraus, A., and Raman, R. (1998) *GAMS: A User's Guide, GAMS Development Corporation*, Washington, D.C.

Chewings, R.A. and Pascoe, S. (1988) Demand for Water in the Murray Valley, New South Wales: An Application of Linear Programming, *32nd Annual Conference of the Australian Agricultural Economic Society*, La Trobe University, Melbourne, 8-12 February.

Doll, J.P. and Orazem, F. (1984) Production Economics: Theory with Applications, 2nd edn., John Wiley and Sons, Brisbane.

Kheper, S.D. and Chaturvedi, M.C. (1982) Optimum cropping and groundwater management, Water Resources Bulletin, 18(4): 655-660.

Mainuddin, M. and Gupta, A.D. and Onta, P.R. (1997) Optimal cropping planning model for an existing groundwater irrigation project in Thailand, Agricultural Water Management, 33(1): 43-62.

McCown R.L., Hammer G.L., Hargreaves J.N.G., Holzworth, D.P. and Freebairn D.M. (1996) APSIM: A novel software system for model development, model testing, and simulation in agricultural systems research, Agricultural Systems, 50(3): 255-271.

NBWB (North Burdekin Water Board) (1998) Profile of the North Burdekin Water Board 1965- 1998, North Burdekin Water Board, Ayr.

Panda, S.N. Kheper, S.D. (1985) Stochastic planning for optimal cropping pattern, Journal of Indian Society of Agricultural Engineers, 20(4): 887-895.

Probert, M.E., Dimes, J.P., Keating, B.A., Dalal, R.C. and Strong, W.M. (1997) APSIM's water and nitrogen modules and simulation of the dynamics of water and nitrogen in fallow systems, Agricultural Systems, 56(1): 1-28.

Qureshi, M.E., Arunakumaren, J., Bajracharya, K., Wegener, M.K, Qureshi, S.E. and Bristow, K. (2002) Economic and environmental impacts of groundwater management scenarios in Burdekin Delta, AARES 2001 (Australian Agricultural and Resource Economics Society) Conference, February 13-15, Canberra.

Qureshi, M.E. Wegener, M.K., Bristow, K.L, Mallawaarachchi, T. and Charlesworth, P.B. (2001) Economic evaluation of alternative irrigation practices for sugarcane production in the Burdekin Delta, AARES 2001 (Australian Agricultural and Resource Economics Society) Conference, January 22-25, Adelaide.

Samuelson, P.A. and Nordhaus, W.D. (1987) Economics, 12th edition, McGraw-Hill, Sydney.

Small, F. (2000) Socio-Economic Costs and Benefits of Cane Production in the Burdekin and Proserpine Districts: Growers Survey Report, Bureau of Sugar Experiment Station, Brandon, Qld.

SBWB (South Burdekin Water Board) (1999) Annual Report of the South Burdekin Water Board: 1998-1999, South Burdekin Water Board, Home Hill.

Thomas, J.F. (1999) Water and the Australian Economy, Australian Academy of Technological Sciences and Engineering, Melbourne.

Tisdell, J.G. (1996) The Price of Irrigation Water, Economic Analysis and Policy, 26(1): 95-104.

Ulibarri, C.A., Seely, H.S. and Willis, D.B. (1998) Farm profitability and BUREC water subsidies: An LP look at a region, Contemporary Economic Policy, 16(4): 442-451.

Varela-Ortega, Sumpsi, A.G., Blanco, M. and Iglesias, E. (1998) Water pricing policies, public decision making and farmers'response: implications for water policy, Agricultural Economics, 19(1): 193-202.

Wossink, G.A.A., de Koeijer, T.J. and Renkema, J.A. (1992) Environmental-economic policy assessment: a farm economic approach, Agricultural Systems, 39(4): 42-438.