ECONOMIC EVALUATION OF ALTERNATIVE IRRIGATION PRACTICES FOR SUGARCANE PRODUCTION IN THE BURDEKIN DELTA

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The Burdekin delta in north Queensland is a major irrigation area producing over 35,000 ha of irrigated sugarcane and other crops. This area is unique because it overlies shallow aquifers and relies heavily on groundwater supply for irrigation water. The long-term 'health' of the groundwater systems is therefore critical to the economic and environmental well being of the whole region. The Delta Water Boards are responsible for the management and replenishment of the groundwater systems, and promote a total systems approach in the development and adoption of best practice irrigation options. Application of economic analyses can assist in determining private and social benefits of irrigation management options. In particular, detail economic modelling can incorporate the scarcity of water resources, its social opportunity cost, and evaluate alternative water management otions to maximse net social benefits. A multi-period mathematical programming model is therefore being developed to estimate the responsiveness of water demand to price changes and to alternative water management and irrigation practices. This paper presents preliminary results of economic modelling, the aim being to improve understanding of likely impact on income levels of growers and the Water Boards when growers are encouraged to adopt more efficient irrigation practices.

Introduction
Water is one of the most important factors limiting the development of agriculture. All over the world, water is becoming an increasingly scarce resource and therefore limiting agricultural development in many regions and countries. In the past, building new physical systems to harness spatially and temporally distributed water resources has been the common policy. Decision makers fostered these policies by developing irrigation and attempted to guarantee the supply of water. However, with supplies dwindling and harmful externalities of irrigation being apparent, emphasis is now being placed on the need to improve the performance of existing irrigation systems. Efficient and sustainable management of water resources is increasingly becoming a global policy objective. Other reasons which have driven community aspirations for efficiency improvements and change are declining quality of land and water resources across irrigated regions, diminishing terms of trade for farming industries and changing demand and supply conditions for agricultural commodities.

Australian governments have responded by endorsing the goal of improved efficiency and this has resulted in the development of a comprehensive water sector reform program, which includes a move towards complete cost recovery. As a result, farmers are

facing increases in water charges. This is happening at the time when many growers encountering narrowing profit margins caused by escalating production costs and declining commodity prices. Farmers would be expected to maintain profitability under these conditions by adjusting their operations to gain productivity improvements and achieve cost savings.

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. This decision need to be based on the quality and availability of water resources, reliability of water supply, the physiological requirements of the crop, and the expected value of output. An important strategy for the application of water to crops is to apply irrigation water at a level that gives maximum net income. Achievement of that strategy rests with more efficient use of irrigation involving water saving technology as opposed to traditional irrigation systems that were designed to favour maximum crop growth. It has been considered that policies affecting the demand for water (demand side approach) can increase the efficiency of water use (Cummings and Nercissiantz, 1992), and adoption of modern irrigation technology is often cited as a key to increasing water use efficiency while maintaining current levels of production (Cason and Uhlaner, 1991; Green, et al., 1996). One of the key policy instruments that has been analysed in the literature is the establishment of water prices to determine the patterns of response in the use of water in agriculture (Wilchens, 1991; Cummings and Nercissiantz, 1992; Rosegrant et al., 1995).

As noted in Caswell and Zilberman (1983), modern irrigation technology is a land-quality-augmenting technology where capital equipment assists the land in its water holding function, thus increasing irrigation efficiency. The industry is assumed to be competitive and farmers are profit maximisers. The optimal water use level is determined by maximising the operational profit per unit area. The profits under both technologies are compared and more profitable technology is selected (Zilberman, 1984). The modern irrigation technologies are often more expensive (require heavy initial investment) and are less profitable than the traditional irrigation systems, and irrigators are generally reluctant to adopt the new system.

Although it has been discussed in the literature that water pricing policies can induce adoption of modern irrigation technologies and lead to substantial water saving (Caswell and Zilberman, 1985; Caswell, et al., 1990), there is evidence that there are other factors that outweigh these pricing effects; including crop diversification potential, magnitude of the water allotment, the risk involved in water delivery and water quality (Varela-Ortega, 1998). The ability of irrigators to adopt a more efficient irrigation system also depends on financial and resource characteristics of the farm, farmer's business goals and their attitudes to risk. The range of production possibilities available, the optimal mix of production inputs and the profitability of alternative enterprises will change over time because of the dynamic nature of a farm's operating environment. The long-term viability of farm businesses will also depend on the returns obtained from the adoption of new technology, the potential for expansion of farm operations, and the capacity to identify and adjust to the optimal mix of enterprises (Mallawaarachchi, et al., 1992). An

understanding of the level and distribution of current financial performance of irrigators, and their ability to adapt to changing circumstances will be important aid in determining the extent of impacts, the likely adoption costs and the constraints to adoption. This information can then be used to either refine existing policies or to develop complementary policies to facilitate change.

Economic models designed for policy analysis are generally used to assess the effectiveness of policies through an examination of target group response to them. This could be achieved through simulation, forecasting or scenario evaluation, depending on the modelling technique employed and the nature of data, resources and personnel available. Modelling long term policy and investment options involves a complex configuration of issues. The issues facing policy makers include a choice among a set of alternative options, meeting constraints on resources, environmental concerns, time frames and cost effectiveness (Mallawaarachchi et al., 1992). On the response side, it is primarily a question of forecasting likely response by producers to the proposed policies. Much of this can be incorporated in a mathematical programming structure. The modelling approach CANEPLAN described in this paper resembles the MIPMOD model developed by ABARE researchers (Mallawaarachchi et al., 1992) and a Spanish model (Varela-Ortega, et al., 1998).

CANEPLAN is designed to undertake economic analysis of alternative irrigation systems for a sugarcane farm with different soil types, including the evaluation of the current irrigation system. It is planned to use this framework in two case study farms in the North and South Burdekin Water Board Areas. CANEPLAN is a multi-period optimisation (linear programming) model designed to reflect farm level activities in the sugar industry in the Burdekin delta area. The CANEPLAN model is used to evaluate the effects of changes in water charges and output prices on sugarcane farmer investment in farm development through irrigation system improvements from flood to centre pivot or drip irrigation.

This paper presents a detailed description of the modelling approach adopted for the analysis of irrigation systems and impact of various water charges on a grower's income and adoption of modern irrigation system/s. In particular, this paper will address the changing strategies that farmers might follow to adopt new irrigation techniques. The modelling system provides a framework to assess the long-term response of sugarcane growers to change in their operating environment. In the next two sections, issues in the case study area and need for effective irrigation management are discussed. The analytical framework used in the current study is discussed in the next section. Then results are presented and discussed. Conclusions and policy implications are presented in the last section.

Burdekin delta study area and its irrigation system
The Burdekin River delta has an area of about 850 km^2 and is located on the northeast coast of Queensland, Australia (Figure 1). It is approximately 90 km southeast of Townsville and includes townships of Ayr, Home Hill and Brandon. The Burdekin River Delta and the Haughton – Barratta system together make up one of the largest alluvial

aquifer systems in Australia. The delta region is confined to the unconsolidated sediments formed by the overflow deposition from the Burdekin River and its distributaries. It is a large cuspate delta overlying a mostly granite basement with a sedimentary formation in excess of 100 metres deep. These sedimentary formations constitute the aquifer[1] body that contains the region's groundwater supplies. The groundwater system within the Burdekin delta aquifer is considered to be unconfined (i.e. no impermeable overlying sediments) and is therefore open to recharge from the surface (Arunakumaren et al., 2000, Ch. 3, p. 14).

Figure 1: Map of Burdekin Delta.

Topography of the delta is flat to slightly undulating; however outcrops of basement rock occur in the south and southwest of the delta. The land surface slopes gently towards the ocean with surface water and groundwater discharging into the ocean to the east and the north. Approximately one third of the delta lies south of the Burdekin River (right bank) and two third north of the river (left bank). Rainfall in the delta is seasonal with average annual values of around 1000 mm while the total rainfall varies from 250 mm to 2500 mm. Over two thirds of the annual rainfall occur during the months of January to March. The delta area features a tropical climate with hot summers and mild winters. Evaporation varies from 10 mm/day (high) in November to 2.8 mm/day (low) in June (Arunakumaren, et al., 2000).
The delta is predominately used for sugarcane production, with some other areas under mango, citrus, tropical fruit and vegetable farms. A small proportion of the delta area

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[1]   Groundwater collects in porous layers of underground geological formations known as aquifers.

where groundwater and/or soil quality are not suitable for sugarcane is used for cattle grazing. The production of commercial sugar commenced in 1883 while irrigation practices began in 1887. Sugarcane became the major crop in the delta because of its dry clear climate for much of the year and the availability of water as well as the suitability of deltaic soils for sugarcane. The demand on shallow groundwater supplies increased rapidly as the area under sugarcane expanded. An extended drought in 1930-35 caused alarming reductions in groundwater levels below sea level causing seawater intrusion. In 1962-63, despite excellent rainfall, it was clear that there was a situation of water overdraft in the delta which resulted in a decline in groundwater levels. Investigations into the problem revealed a deficiency of about 108,000 to 150,000 ML to service the level of cane production area in 1964. Test drilling revealed an extensive aquifer system which when full would represent a storage in excess of 1.23 million ML. A further study of the aquifer system deemed it possible to replenish this underground basin artificially (NBWB, 1998). This situation resulted in implementation of an artificial groundwater recharge scheme by the Queensland Department of Natural Resources (formerly Irrigation and Water Supply Commission) by establishing the North and South Burdekin Water Boards in 1965 and 1966 respectively.

The recharging scheme involves the use of electric pumping plants to divert river water to suitable recharge areas through a system of natural and artificial channels. Sand dams are constructed in the Burdekin River during periods of low flow in the river and are used to help maintain practical operating levels at river pump stations by containing releases from upstream storages. Farm water practices such as 'recycling', 'water spreading' or direct pumping from recharge channels to farms in some parts of the district have also evolved to play an integral role in the management of the groundwater systems. 'Recycling' refers to the practice where irrigation water from private production bores that is not used by the plants (excess irrigation) returns through the soil back to the groundwater to maintain groundwater levels. 'Water spreading' refers to the practice where water pumped from river by the boards, is too turbid to be used for artificial recharge through the recharge pits and is made available as surface water for farm irrigation. This helps in spreading the silt load across the farmland and, while keeping the silt out of the recharge pits, is thought to be beneficial to the soils and assists the replenishment process (Bristow et al., 2000). A number of external studies on the Burdekin Delta area are available and they mainly focus on research projects on the siltation and clogging of artificial recharge channels and pits. O'Shea (1985) discussed these studies and concluded that the Recharge Scheme had been operating successfully since its inception in 1965. This scheme is entirely financed by the local cane growers and the milling company. The costs of supplying irrigation water are recovered by levies on sugarcane production (i.e. t/ha). According to the current water charging arrangements, two-thirds of the levy is paid by canegrowers and one-third by the milling company. Other crops grown are rated on the basis of a levy equivalent to sugarcane

In the Burdekin delta, management of the aquifer is critical and challenging because it overlies shallow major groundwater supplies and relies heavily on these supplies for irrigation water. Also, the area is situated in close proximity to environmentally sensitive wetlands, waterways, estuaries, and the Great Barrier Reef, and water charging and water

management practices have evolved in response to local needs (Bristow et al., 2000). Therefore, it is important to review current management practices, and design and implement new and improved practices to ensure the long-term viability of irrigated agriculture in the region. Effective management also requires research to examine possibilities for improvement.

The Delta Water Boards have been actively participating and supporting research projects carried out by various individuals and organizations to examine the potential issues, such as saltwater intrusion and groundwater contamination. A consultant engaged by the North and South Burdekin Water Boards reviewed a number of issues relevant to the Boards' interests (SK&M, 1997). The major issues identified by this study were rise in water table levels in some areas, especially in the NBWB area, an increase in groundwater salinity in some sections of the delta due to the presence of saline water inflow, and seawater intrusion in deeper aquifers. This study argued that seawater intrusion was a significant threat and potential limiting factor on the sustainable level of groundwater extraction in the long term. The study further argued that effective groundwater management would be limited by the absence of water metering and lack of records of the location of private irrigation bores, pumping rates from the bores, annual pumped volumes, and information on the performance of the aquifer. In recent years, the boards have started to shift emphasis from purely recharge to groundwater management via conservation. This is particularly important in areas operated by the NBWB. The aim of this approach is to encourage growers to take open water directly from the board's distribution system to reduce pressure on the groundwater aquifer (NBWB, 1998).

Effective irrigation management
Irrigation has allowed the expansion of agriculture into semi-arid and even arid environments, thus helping to stabilise the revenue from farming. With the exception of crops with low added value, irrigation can bring substantial economic gains (Bonnis and Steenblik, 1998). In sugarcane, irrigation plays an important role in increasing efficiency of farm management, enabling timely preparation of land, rapid establishment of plant and ratoon crops, improving efficacy of herbicides, reducing pest and disease related stresses and avoiding ammonia volatilisation from surface applied fertilisers such as urea (Kingston et al., 2000). Potential impacts from poor irrigation management include increased salinity and sodicity, rising water tables, waterlogging, nutrient and pesticide pollution of waterways, and alterations to the biological populations in streams (Kingston et al., 2000). Irrigated agriculture affects water quality in several ways including higher rates of chemical use associated with irrigated crop production, increased field salinity and erosion due to applied water, accelerated pollutant transport with drainage flows, degradation due to increased deep percolation to saline formations, and greater instream pollutant concentrations due to reduced flows (USDA, 1997).

Excessive use of groundwater aquifers can lead to higher concentrations of pollutants. Excessive extraction can lower water-tables leading, in some cases, to ground subsidence and, in some coastal areas, to salt-water intrusion. Moreover, because irrigation water almost always contains much higher concentrations of dissolved salts than rainwater, its

discharge often raises the proportion of salts in the bodies of water into which it flows (Bonnis and Steenblik, 1998).

The depletion of aquifers by irrigation raises questions about the sustainability of farming systems. In the Texas High Plains of the United States of America, agriculture has been responsible for depleting one-quarter of the Texas portion of the massive Ogallala aquifer. Another threat to the sustainable management of agricultural land is the lack of adequate drainage, which farmers and governments also fail to provide because of its expense. Too often, the result is water logging and the build-up of salt in the soil. In places such as the Iberian Peninsula, some parts of southern Australia and western North America, fertile lands have had to be abandoned due to salt concentration, nullifying some of the gains that irrigation was intended to yield (Bonnis and Steenblik, 1998).

Irrigation management and efficiency
Effective irrigation management is vital for irrigated crop production. It is essential for sustainable utilisation of the resource and management of potential ecological impacts. Effective management of irrigation can minimise ecological impact of irrigation, conserve water supplies and improve producer net returns. Best irrigation management practice requires growers to be more efficient in irrigation. Current assessment of water use efficiency (WUE) in Queensland indicates that about 60% of irrigation water is used by crop or pasture production and the remainder is lost due to run off, drainage and evaporation (Barraclough & Co, 2000).

The Burdekin is one of the regions in Queensland where cane is grown under full irrigation, and its average yield is about 123 t/ha (highest in Australia). However, the average use of irrigation water is also the highest in Queensland, i.e. 8 to 15 ML/ha. One of the reasons for such high water use in the delta is the furrow irrigation system adopted on highly permeable soils. Studies indicate that irrigation application efficiencies for furrow irrigation varied from less than 20% to nearly 70% (Holden et al., 1998, reported in Tilley and Chapman, pp. 28-29). To produce one tonne of cane per hectare, approximately 300 mm of water (0.30 of a ML) is used. However, this inefficient use of irrigation water is believed to assist in maintenance of the aquifer. The inefficient application raises several issues of social as well as private costs. If growers are more efficient and use less water for irrigation then more water will be available in the aquifer for future irrigation use. There will also be potential to use the saved water for other agricultural crops and other activities. Efficient irrigation practice will save the growers' pumping costs and there will be less potential for the leaching of nutrients and pesticides to the aquifer.

The need for a strategic approach to manage water (including efficient water use for irrigation) has been recognised both at the national and state level. In 1994, the Council of Australian Governments (COAG) adopted a National Water reform Agenda. This represents the first nationally coordinated strategic approach involving Federal and State governments in implementing agreed reforms based on a common strategic vision. The reforms in the rural sector seek to ensure an economically viable and ecologically sustainable water industry. It is argued that business as usual in the rural water industry

will not be a viable option for irrigators or the environment on either a medium or long-term basis. The agenda integrates elements of ecologically sustainable development and the National Competition Policy and is to be implemented by 2001 (Prime Minister's Science and Engineering Council, 1996).

The agenda calls among other changes for pricing water based on transparency and full-cost recovery; setting up a comprehensive system of allocating water or entitlements to water-use distinguishing between property rights on water and on soil; allowing exchange of water-allocations and of entitlements to water-use within social, physical and ecological constraints. In parallel, changes are proposed to the way that public water-supplies are managed so as to ensure that natural wetlands receive adequate quantities at the right time (Bonnis and Steenblik, 1998). This means that current prices paid for water are likely to rise, and in some cases, have already done so. However, full cost recovery means farmers and businesses will have more confidence that their surface water and groundwater sources will be managed sustainably. There will also be improved operational efficiencies arising from changes to the way water is managed and delivered, including approaches such as corporatisation, privatisation and the creation of a Murray Darling Basin Water Business (AFFA, 2000).

The changes to institutional structures are likely to offset the effects of price increases that might occur as a result of reform. The reforms will also help to identify the real value of water and make clear any subsidy or community service obligation so that the decisions can be made about how best to use and protect valuable resources. It is expected that industry performance will also be improved through the transference of responsibility to irrigators to allow them to influence levels of service and to ensure that water delivery matches production needs (AFFA, 2000).

Recently, the Queensland Department of Natural Resources developed a $41 million Rural Water Use Efficiency initiative. The initiative is a partnership agreement between rural industries (including the sugar industry) and the government to improve the water use efficiency and management of available irrigation water thereby improving the competitiveness, profitability and environmental sustainability of Queensland's rural industries (Barraclough & Co, 2000). The major aim of the RWU initiative is to place more emphasis on water use efficiency and wastewater use.

Various management practices and irrigation technologies are available to enhance efficiency of applied water in irrigation agriculture. Irrigation improvements often involve upgrading physical systems to improved field application efficiency and to achieve higher yield potentials. Improved irrigation management practices, such as irrigation scheduling and water-flow measurement, may also be required to achieve maximum potential of the physical system. In addition, management of drainage flows may be an important in many irrigated areas. In some cases, the effectiveness of improved irrigation practices may be enhanced when implemented in combination with other farming practices such as conservation tillage and nutrient management (USDA, 1997).

Irrigation technology choice
The ability of the irrigation system to apply water uniformly and efficiently to the irrigated area is a major factor influencing the agronomic and economic viability of the production system. Irrigation application systems may be grouped under two broad system types: gravity flow (such as flood/furrow) and pressurised systems (such as centre pivot and drip/trickle). Typical application efficiencies for the most common irrigation systems indicate that higher efficiency can normally be expected through the use of micro-irrigation or low-pressure overhead spray systems. However, substantial water losses occur where these systems are being used with inappropriate management practices (Raine and Foley, 1999). The efficiency of water use can be defined for each of these systems based on the volumetric water inputs and outputs, or uses and losses. Potential volumetric losses (or inefficiencies) within these systems must be measured accurately to quantify whole farm water use efficiency. Volumetric measurements of the water flows into and out of each unit are required and include groundwater and riverine flows, scheme supplies, rainfall, seepage (or percolation), evaporation, overland flows and tailwater recycling (if applicable) (Raine, 1999, Ch. 1). A brief description of three of the most common irrigation systems, namely furrow, centre pivot and trickle, is given below.

Furrow irrigation is the most widely used system for irrigating sugarcane in Queensland. In the Burdekin, 99.5% growers have furrow irrigation systems. It has low capital costs, is simple to operate and is suitable for land with less than 3% slope. Application efficiency for furrow irrigation varies from 10% to 90%. This system is popular where topography, soil type and availability of water permit.

Across Australia, and around the globe, the primary factor that has led to a change in irrigation practice from traditional flood/furrow method to the water intensive systems such as drip or trickle is the supply controls on water. Quantitative restriction on water harvesting, delivery and use has forced irrigators to use less water, so that water saved can be used later, or used in another area. On the other hand, qualitative restrictions may improve a farm due to actual or potential increase in water quality and reduction in salinity. In Queensland, growers have made the great changes to their irrigation systems and adopted better irrigation practices in areas where irrigation water supplies are limited. For example, the increased salinity of the aquifer in parts of the Mackay canegrowing area has reduced available irrigation water supplies and convinced many growers to change from furrow to overhead irrigation systems. Similarly, water shortage from the Bundaberg Irrigation Scheme forced many growers to improve their application efficiencies. Furrow irrigation has the greatest potential for deep drainage losses and anecdotal evidence suggests that long-term use of furrow irrigation is contributing to a rise in watertables and increased salinity in the Burdekin River Irrigation Area and on the Atherton Tableland (Tilley and Chapman, 1999).

Growers have no incentive to improve efficiency of application where water is readily available at low cost. The major components of water cost are electricity and levy charges. However, the growers consider that higher pumping costs are offset by lower management costs and the perceived long-term benefits of aquifer recharge through deep

drainage. With long furrows and no tailwater recycling, many growers continue to apply water after it has reached the end of the furrows to ensure that the soil in the root zone is completely recharged. Without close monitoring of time required to recharge the soil water deficit under commercial conditions, a significant component of the irrigation water applied may be lost as excessive runoff (Tilley and Chapman, 1999).

Centre pivot (a low pressure overhead system) is attracting increasing interest, particularly where irrigation water supplies have become limited. The advantages of this system are the ability to automate, an easily varied application rate, and a uniform distribution pattern, even under relatively windy conditions and large areas can be covered in one operation. Liquid fertiliser is usually applied through this system. These units have low operating costs due to the low pressure required and a low labour requirement. Being low pressure, these units can use low quality piping. However, the major disadvantage of this system is its relatively high initial capital cost.

The drip or trickle irrigation systems have the potential to deliver more than 95% application efficiency provided they are managed correctly. Water is delivered to the plant root zone via thin walled tubing laid either on top of or below the soil surface. Emitter pores along the length of the tube regulate the flow of water. These tubes are connected to a mainline system that is in turn connected to a filter system. The whole system operates at low pressure and allows small amounts of water to be applied to large areas as required. The system lends itself to automation and is used for fertigation. Thorburn et al. (1998) reviewed literature on the productivity of sugarcane under trickle irrigation system, with particular attention to water and nitrogen management. They found that early research showed few advantages of the system, however studies published since the mid 1980s have shown yield increase of 5% to 20%. A small number of studies have found irrigation efficiency has increased by 50% to 80%.

This system can be a an efficient means of applying crop nutrients, so nutrients application rates may be reduced in this system. A recent study found that this system significantly increased crop and sugar yield with less application of nitrogen (75% of the industry standard). Apart from reduction in nitrogen applications, the system allowed in-crop adjustment to nitrogen management to overcome problems such as loss of nitrogen in wet periods. This system is an economically and environmentally advantageous means of managing nitrogen compared with continual over-fertilisation (Dart, et al., 2000). This system is most expensive and its installation cost (more than $4000/ha) and poor water quality are the major barriers to widespread adoption. In addition, the system requires a high level of management expertise to gain the full benefits of potential irrigation application efficiency.

Adoption and long run use of one of these irrigation systems depends on a number of factors including site characteristics such as soil permeability, slope and overall irrigation efficiency, impact on yield, installation and operating costs, water charges and concern for the local environment (such as impact on aquifer and ground and surface water quality). It also depends on initial capital available to a grower in the form of savings, rate of interest for borrowing and off farm investment as well as on government

regulations and financial support programs. Therefore, an integrated approach is required to examine agronomic, economic and environmental factors.

The Australian Income Tax Assessment Act contains certain provisions to encourage development of water resources and investment in irrigation infrastructure. The government provides these incentives to help stabilise income from primary production, facilitate self-reliance, and hence reduce the need and cost of government support during drought. Aspects of the act incorporated in the current model include marginal income tax rates and income splitting. Section 51(1) provisions allow primary producers to write-off irrigation investigation and planning costs and all irrigation operating costs in the year of expenditure. Section 75B provisions allow growers to depreciate the capital costs associated with irrigation storage and reticulation works over three years. Drought Investment Allowance allows primary producers to claim an additional deduction of 10% of the capital costs (up to a maximum deduction of $5,000) associated with irrigation reticulation (excludes storage for irrigation) in the year of expenditure (Schuurs and Wegener, 1999).

Technological innovations can improve the physical productivity of capital assets, thus influencing potential production capacity and the optimum stock of capital (Mallawaarachchi et al., 1992). Centre Pivot and trickle (drip) irrigation technologies are considered along with the *status quo* (current system) in the present analysis.

Analytical framework and data collection
The integrated approach used in this analysis includes using the output from a biophysical simulation model to predict crop yields of sugarcane (the only major crop in the region) under different irrigation levels linked to a linear programming model to assess water price implications for a representative farm in the study area. A detailed description of the analytical framework and its components is presented in this section.

Biophysical models
For a comprehensive economic analysis, biophysical information (such as rainfall, temperature, humidity, water holding capacity, water level and crop yield) is necessary. Currently, there is no information available on the impact of different irrigation systems on crop yield on different soil types in the region. Therefore, biophysical simulations were performed using the APSIM systems model (Agricultural Production Systems Simulator; McCown *et al*., 1996) to estimate yield responses to applied irrigation across a range of irrigation options. In this study, the sugar crop module APSIM-Sugarcane (Keating *et al.,* 1998) was linked with the soil water module SOILWAT (Probert *et al.,* 1997), the soil nitrogen module SOILN (Probert *et al.,* 1997), and the surface residue module RESIDUE (Probert *et al.,* 1997) to investigate yield responses to applied irrigation across a range of irrigation options. 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 selection of irrigation options were chosen for investigation based on combinations of soil types, allocation (0 to 35 ML/ha in 1 ML/ha increments) and above-ground application efficiencies for three irrigations methods for three soil types which varied from 30% to 90%, as shown in

Table 1. The three soil types (Clay, Silt and Sand) used in the simulation were selected to represent profiles with sharply contrasting plant extractable soil water contents. These soil types have been considered representative of low, medium and high permeable soil types in the study area.

Table 1: Efficiency of irrigation system in different soil types

Irrigation system Soil type	Furrow (efficiency %)	Centre Pivot (efficiency %)	Ttrickle (efficiency %)
Low Permeable	60	90	90
Medium Permeable	50	80	85
High Permeable	30	75	80

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

Linear programming mathematical model
Linear programming (LP), a technique based on matrix algebra that is capable of producing mathematical solutions in terms of maximising or minimising stated objective (Bekene and Winterboer, 1973; Romero and Rehman, 1989), has been used to develop the CANEPLAN model.[2] The CANEPLAN has been developed in GAMS (General Algebraic Modelling System) (Brooke et., 1998). The model closely follows the ABARE multi-period investment programming model MIPMOD (Mallawaarachchi et al., 1992) which was used to examine likely investment in water saving irrigation technology at different crop prices and input costs. A useful discussion about multi-period linear programming models (of investment) is given by Dent et al (1986), including an example of a multi-period model with tax savings and progressive taxation arrangements. A similar model was developed in Spain to analyse the effect caused by the application of different water pricing policies on water demand, farmers' income and the revenue collected by the government agency (Varela-Ortega, et al., 1998).

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[2] Mathematical programming methods are well suited for economic analysis because; (a) many activities and restrictions can be considered at the same time, (ii) an explicit and efficient optimum seeking procedure is provided, (iii) with a once-formulated model, results from changing variables can be calculated easily, (iv) new production techniques can be incorporated easily by means of additional activities in the model (Wossink et al., 1992), and (v) the method does not depend upon time series data which is necessary condition for econometric modelling, thus enables to predict impact on demand of a commodity due of various prices and under different institutional constraints (Chewings and Pascoe, 1988).

The CANEPLAN model is designed to reflect the sugar industry in the Burdekin delta area. It is used to evaluate the effects of changes in water charges and output prices on sugarcane farmers' investment in farm development through irrigation system improvements from flood to centre pivot or drip irrigation. The model is designed to represent an average farm in either North or South Burdekin Water Board Area as both these boards are dealing with similar issues and relying on a levy on production ($/t) as far as groundwater charges are concerned and on a volumetric basis ($/ML) for surface water. However, there are differences in the structure of ground water charges (levy) between the two boards and limit (threshold) of water for low-rate and high-rate charges which are based on volume of water used per hectare. In the case of NBWB, the groundwater levy on yield is $0.80/t and for low-priced water the threshold is 8 ML and water charges are $4.80/ML while beyond this level the water charges are $22.20/ML. In the case of SWB, the levy is $.50/t and low-water threshold level 4ML/ha while water charges up to this level are $5.40 and beyond this level are $13.67. The other major difference between the two jurisdictions is the proportions of groundwater and surface water, owing to technical reasons rather than economic or financial reasons. These reasons include quality of groundwater and need to recharge the aquifer. In NBWB, the proportion of groundwater and surface water are 40% and 60%, while in case of SBWB, these proportions are 70% and 30% respectively (i.e. a NBWB cane farm uses less groundwater than a cane farm in SBWB area). These restrictions have been imposed and observed in the analyses by changing parameter values for the two representative farms.

The economic model attempts to reflect the viewpoint of the individual cane farmer as a member of irrigation community. The representative farm size is 60 ha with a crop cycle of 4 years (one plant and three ratoon crops), and 20% of the farm area is fallow in each year. The crop yield from each soil type and for each irrigation system simulated by APSIM (discussed above) has been used in the analysis. The area under each soil type from the whole farm has been estimated on the basis of proportion of the three soil types (i.e. 33% low permeable, 56% medium permeable and 11% high permeable) in the study area (Arunakumaren, et al., 2000). To reduce the complexity of the model, the analyses used average yield of plant and three ratoon crops (i.e. only one crop activity), obtained by APSIM model.

Following assumptions made in previous studies (Mallawaarachchi, et al., 1992; Varela-Ortega, et al., 1998), it is assumed that farmers are risk neutral and their objective is maximisation of profit from their income generating activities. It is also assumed that farmers' investment decisions are secondary to meeting their immediate family needs. Therefore, the model provides for after-tax drawings of $17 776 per annum (at the rate of $341.90 per week). Farmers may also have a discretionary consumption for family goals. In the allocation of post-tax surpluses, the balance between discretionary consumption and investment is a problem of capital rationing, which can depend on a number of factors including family wealth, farm enterprise, stage of development, risk attitude, and current income. According to Freebairn (1977), the annual marginal propensity to consume of Australian households during late 1940s to mid 1970s varied from 0.4 to 0.6. This analysis used 60% (of post-tax surpluses) as investment and 40% as consumption.

The farm has $25000 available for investment and, in addition, farm borrowings are allowed as ten year term loan during the development phase at an interest rate of 10% per annum. The farm is allowed to invest working capital surpluses in a savings account at the rate of 5% per annum.

Data acquisition
Particular care has been taken to gather data on technical and economic systems of the farms in the study area. Information was obtained from published literature, various public departments and organizations, water boards, farmers and their organisations, irrigation as well as from various irrigation and other business organizations. An attempt was made to verify the information and data from various sources and informal discussion was held with local farmers and representatives of various organisations.

Fixed operation cost of $20000, estimated by the ABARE Farm Survey has been used in the analysis. The data on water charges and about the threshold payment structure of the two boards were obtained from material published by the water boards and updated through correspondence. The data about sugar production costs (including planting, fertiliser, herbicide, insecticide, tractor use and harvesting) were obtained from a survey report compiled by the local BSES office (Small, 2000). Similar information was also obtained from the local office of CANEGROWERS. The electricity charges were obtained from the water boards and were estimated on the basis of the appropriate electricity tariff rate and pumping costs for groundwater as well as surface water. The information about labour hours available, labour hours used and costs for each hour were estimated after discussing with growers and from the office of their association. Data about sugar content (which is key in the sugar price formula) were obtained from the local sugar mill and an average of past 10 years was used in the analysis. Similarly, average pool price of sugar in Queensland was used in the analysis. The costs of irrigation system were obtained from the local and regional irrigation systems and equipment supplier (McCrackens, Mareeba, *pers. comm.*). The analysis used 90% of the agronomic yield of the crop to represent an economic optimum (which comes at lower level of input and depends on cost of input and price of output) for three different soil types and irrigation systems. No attempt has been made in the analysis to determine optimum level of water use endogenously, due to data restrictions.

Objective of the model
The objective function is designed to maximise the net cash surplus at the end of the planning horizon, subject to annual operator drawings and discretionary consumption of annual post-tax surpluses. The model estimated net profit after tax and evaluated investment in irrigation technologies within the context of the whole sugarcane farm business (rather than as a project in isolation) on a representative farm. The model identified the long run equilibrium solution to the optimisation problem and evaluates the investment decisions for two irrigation technologies (centre pivot and trickle) and compares them with the current furrow irrigation system. It is to be noted that allocation of some area under one system and the remaining area under other system/s was not realistic on a farm of 60 ha only, and it is neither technically nor economically feasible to

allocate area to more than one system. Therefore, a binary condition was imposed to allocate the entire area under one system.

The planning horizon chosen consists of 20 single year time periods that are grouped into a ten-year farm development phase followed by a ten-year stabilisation phase. This stabilisation phase allows maximum sustainable yields of all crop enterprises to be reached (Mallawaarachchi et al., 1992). The analysis does not consider any capital appreciation as the irrigation systems are assumed to depreciate over the period of the planning horizon of 20 years. It is assumed that investment will take place during the fallow period and no disruption will take place in the crop cycle of the sugarcane.

The income generating activities of farm income and investment of surplus working capital in the savings account in each year contribute to a single row in the linear programming matrix from which all the farm operating expenditures are deducted. This results in gross profit before tax. The capital is depreciated to obtain taxable income in each year. Taxation has been included with a progressive tax structure based on linear segments. This is channelled through a sub matrix which simulates the income tax to calculate the tax liability and post-tax surpluses which are available for consumption and investment in the following year after deducting compulsory operator allowance. Provision for tax deductions allowable for capital investments on irrigation improvements (discussed earlier) have been made for the first three years at the rate of 33% each year.

All the capital and current expenditure items are recorded as separate cash flows. Investments may be made on-farm and/or saved in the bank during the first ten years of the planning horizon but are limited to savings only during the last 10 years. This flow of funds is repeated in each year until the 20th year, which is the end of the planning horizon. The model screens out the activities that generate lower rates of return compared to the market opportunity rate which is specified exogenously as the returns to off-farm investment of annual investable cash surpluses. The activities are compared on a post-tax basis, both among farm activities and the market opportunity rate. The analysis has used a real rate of 5% for savings while a rate of 10% has been used for borrowing. It is assumed that the farm is owned and operated by a farm family, and a single tax payer is assumed for tax purposes.

Results and discussions
Results from the preliminary analyses indicate some interesting trends that will help explain the behavioural response of farm managers choosing to adopt more efficient irrigation technology. Irrigation technologies have been appraised in a series of simulation experiments in which the values of key parameters have been altered systematically. Basically, a series of changes in sugar prices, water charges, interest rates, capital investment costs, and other important variables have been examined to see their effect on the optimal investment decision and there is a strong tendency to change from flood irrigation to the more efficient centre pivot system. Trickle irrigation was not selected as a strategy under any of the combination of input values that were tested, except when its capital cost was reduced by 42%.

To simulate the impact of each parameter, the prices and costs have been changed one at a time by keeping others at base levels. The base price of sugarcane, groundwater levy on production and electricity costs of pumping groundwater and surface water have been altered by + and - 20% from the base values. The impact of surface water charges has also been examined by altering their values and increasing them up to 200%. The impact of structure of the farm ownership on taxable income has also been examined by altering the base case of single ownership to partnership between two family members. The borrowing interest rate of investment has been increased and decreased from the base case of 10% to 7% and 13% respectively. Table 2 indicates the parameter values used in base case scenario and the altered values of these parameters. At the base values, the net surplus at the end of 20 years is $115 600 and the total area remains under furrow irrigation until Year 5. Investment in the new system starts in Year 6.

Table 2: Base case parameter values and altered values

Variable	Unit	Base value	Altered values	
Sugar Price	$/t	325.00	260.00	390.00
Groundwater charge	$/t	0.50	0.25	0.75
Surface water charge type one	$/ML	5.40	10.80	16.20
Surface water charge type two	$/ML	13.67	27.34	41.01
Groundwater electricity cost	$/ML	9.11	7.28	10.93
Surface water electricity cost	$/ML	4.00	3.20	4.80
Borrowing rate	%	10.00	7.00	13.00
Farm ownership	sole trader (1) or partnership (2)	1	2	N/A

Higher sugar prices and lower costs generally accelerate the trend towards investment in a centre pivot irrigator but very low sugar prices can mean that the optimum decision is to stay using flood irrigation. When the sugar price is decreased by 20% ($260 instead of $325), the investment in either centre pivot or trickle system does not occur in any year and the whole farm area remains under the furrow system. However, when sugar price is increased by 20% ($390), then the investment in centre pivot system occurs in Year 4.

There is no impact on level of investment when the water levy, electricity charges for groundwater or surface water type two are altered, and investment begins in Year 6. Similar results are found when interest rate for borrowing is altered from 10% to 7% and 13% respectively.

Increasing water charges has the interesting effect of initially bringing the purchase of the centre pivot irrigator forward but if the charges are increased too much, the time of investment is actually delayed. This obviously occurs because the higher water charges initially provide the incentive to switch from the less efficient to the more efficient system. However, if the charges are increased sharply, then the cash surplus from the farm is reduced, and the investment in more efficient technology becomes unaffordable. An increase of up to 100% in surface water type one charges did not have any impact on

investment but when these charges were increased to 200% then investment in centre pivot system occurs in Year 3 of the planning period.

The type of business structure can also affect the optimal decision. When the ownership was changed from single person to partnership between two persons then the investment on centre pivot occurs in Year 8 instead of Year 6, however the net surplus in Year 20 increased from $115600.23 to $193056.65). These results indicate that the partnership has negative impact on investment (which is delayed for two more years) but positive impact on net surplus (i.e. increase in net surplus by $77456.00). These behavioural inconsistencies are attributable to the effect of marginal income taxation which permits a partnership to retain more of its income. Also, taxation provisions on investment favours single ownership because, under same production circumstances, a single ownership will pay tax at a higher bracket, thus allowing a higher discount on investment costs which become tax deductible expenses under accelerated depreciation. Policies designed to encourage the shift to more efficient irrigation methods should operate consistently irrespective of the business structure of the entities that are introducing the innovation.

Implications and conclusions
The integrated approach adopted in this paper captures both economic as well as biophysical impacts of irrigation systems. The analytical framework captures farmers' behaviour in adopting new irrigation technology by allowing for a number of factors affecting investment decisions. This kind of modelling approach could be used to inform farmers about the likely long-term consequences of investment decisions involving modern irrigation technology. The sensitivity analysis of the results achieved by altering various parameters can be useful in analysing farmers' decision processes, and for understanding consequences of prospective policy change. This approach can also be used to examine other farm management options that affect crop yield or sugar price, by adding or subtracting appropriate coefficients in the basic model. The length of planning horizon, proportion of (conjunctive use of) ground and surface water, proportion of soil types, etc. can be altered to suit the problem under investigation. However, the model has some limitations.

The model mimics a private grower's perspective, and does not have the capacity to examine the practice of recharging the aquifer which is a social benefit at the cost of a private grower when over irrigation occurs. In reality, the Water Board encourages the growers to recharge the aquifer through deep drainage and does not consider wastage of water. On the other hand, there is also need to examine the impact of leaching on salinity, groundwater contamination and risk of seawater intrusion which are likely to add to social cost. These topics require further study.

The model can be easily adapted to analyse the impact of farm size. However, because of the lumpy nature of the irrigation investment, the configurations of costs for each irrigation systems need to change accordingly. The model used a binary condition to allow investment on one particular technology rather than investment in combined technologies for the same reason.

The model is based on information and data collected from a number of sources and through meetings and discussions, and reflects average farm management conditions. While in fact, some growers are more efficient than others and there is great variation among them. The model is flexible to take up individual circumstances very efficiently and therefore presents an efficient tool for farm management advice. At a policy level, the framework provides a useful means for examining various scenarios and testing policy options that affect either input costs or output prices of growers. The analysis demonstrates that sugar price, irrigation water charges and ownership structure are key factors which affect the adoption of modern water saving technologies under current policies. The model considers sugar as the only crop in the farm plan without examining any competitive crops which may need less water. Therefore, it is not possible to determine demand for water by altering water charges, and this requires further consideration, as does the inclusion of other competing activities.

The model does not examine the stochastic nature of various decisions/events or non-linear technological and utility relationships and these issues warrant further investigation to take them into account.

The model incorporates data about crop yield and volume of water exogenously and selective figures for an agronomic optimum are used with 90% of the maximum agronomic values without determining economically optimal yield and irrigation level. Further studies can be carried out once experimental results and real data are available about level of water and crop yield. There is also need to determine the economically optimal level of water use which will be affected by input cost and output price.

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