

## **Economic evaluation of alternative irrigation systems for sugarcane in the Burdekin delta in north Queensland, Australia**

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### **Abstract**

The Burdekin delta in Queensland is the most important area for irrigated sugarcane production in Australia. Conjunctive use of groundwater and surface water is commonly practiced in this area, and cane yields are amongst the highest in the nation. However, water consumption per hectare is also high, due to low efficiency of the furrow irrigation system. More efficient irrigation practices would reduce pumping costs for growers, with less potential for salinity and leaching of nutrients and pesticides into the aquifer, as well as reducing the risk of seawater intrusion into groundwater aquifers. New irrigation technologies have greater efficiency but involve high investment costs. Also, growers have little incentive to reduce water use because water charges are low. A bioeconomic simulation model of a typical sugarcane farm in the delta has been used to estimate the relative profitability, in terms of net present value over a 20-year period, for alternative irrigation technologies.

### **Introduction**

Water is becoming an increasingly scarce resource and therefore limiting agricultural development in many regions and countries of the world. In the past, building new physical systems to harness water resources has been the common policy. However, with increase in demand by other than agricultural users as well as harmful externalities of irrigation becoming apparent, emphasis is now being placed on the need to improve the performance of existing irrigation systems. Globally, efficient and sustainable management of water resources is increasingly becoming a policy objective. 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 expected value of crop output. A frequently followed irrigation strategy is to apply water at a level that gives maximum net income to the grower. Adoption of modern water-saving irrigation technology is often cited as a key to increasing water use efficiency while maintaining current levels of production [1,2]. However, this modern technology typically requires greater capital investment, so irrigators are generally reluctant to adopt new systems. Comparison of the relative economic performance of traditional and new irrigation technologies at the farm level requires modelling of costs and returns over a number of years. Such an analysis generally does not take off-farm impacts into account. However, increased water-use efficiency can lead to positive environmental externalities, i.e. social as well as private benefits.

In the next section, the impact of irrigation on agriculture and effective irrigation management in Queensland is discussed. Alternative irrigation technologies used in sugarcane production are then presented. Discussion of pertinent issues in the case study area follows. The analytical framework used in the current study is discussed and results are presented. Conclusions and policy implications are discussed in the last section of the paper.

## **Impact of irrigation on agriculture and effective irrigation management in Queensland**

Irrigation has allowed the expansion of agriculture into semi-arid and even arid environments, thus helping to increase and stabilise the revenue from farming. In sugarcane areas, irrigation enables more timely preparation of land, rapid establishment of crops, improved efficacy of herbicide and fertilizer applications, and reduced pest and disease related stresses [3]. However, negative impacts may also arise, including increased salinity and sodicity, rising watertables, waterlogging, nutrient and pesticide pollution of waterways, and alterations to the biological populations in streams [3]. Irrigated agriculture can increase field salinity and erosion, and adversely affect downstream water quality by encouraging greater use of agrochemicals, the residues of which are transported into watercourses [4].

Excessive use of groundwater can lead to higher concentrations of salts in the soil and thus to salinity. Also, in coastal areas the lowering of watertables sometimes leads to salt-water intrusion, a concern in Central Queensland [5]. The lower watertables increase pumping costs and the depletion of aquifers by irrigation raises questions about the sustainability of farming systems. In some parts of southern Australia, fertile irrigation lands have had to be abandoned due to salt concentration [6]. Well designed irrigation system can minimise ecological impacts, conserve water supplies, and improve producer net returns. Best practice irrigation management requires growers to be more efficient in water use and consider the impact on the environment.

A National Water Reform Agenda was proposed in Australia in 1994 after the Council of Australian Governments (COAG) was established. The reforms seek to ensure an economically viable and ecologically sustainable water industry. It is argued that 'business as usual' in the rural water industry is not a viable option

for irrigators or the environment on either a medium or long-term basis [7]. Among other changes, the agenda calls for water pricing based on full-cost recovery and transparency in setting up a comprehensive system of allocating water entitlements that distinguishes between property rights on water and on soil, and which allows exchange of water allocations between irrigators within social, physical and ecological constraints. This means that prices paid for water are likely to rise, and in some cases, have already done so.

In Queensland (the main cane growing state in Australia), a recent assessment of water use efficiency indicated that about 60% of irrigation water is used for crop or pasture production and the remainder is lost due to runoff, drainage and evaporation [8]. The Queensland Department of Natural Resources has implemented a \$41 million Rural Water Use Efficiency initiative, as a partnership agreement between rural industries (including the sugar industry) and government to improve the competitiveness, profitability and environmental sustainability of Queensland's rural industries [9]. The primary factor that has led to a change in irrigation technology from traditional flood or furrow method to systems such as drip and trickle irrigation has been water supply constraints. For example, the increased salinity of the aquifer in parts of the Mackay canegrowing area in central Queensland has reduced the amount of water available for irrigation and convinced many growers to change from furrow to overhead irrigation systems. Similarly, water shortage from the Bundaberg Irrigation Scheme in South Queensland forced many growers to improve their application efficiencies (defined as amount of irrigation water applied that is available for crop use) [10]. Government tax provisions and subsidies play an important role in directing investment and management practice towards more efficient water use.

## **Alternative irrigation technologies**

The ability of the irrigation system to apply water uniformly and efficiently is a major factor influencing the agronomic and economic viability of the production system. Irrigation systems may be grouped as gravity flow (such as flood or furrow irrigation) and pressurised systems (such as centre pivot and drip or trickle systems). Relative to flood and furrow systems, higher application 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 [11].

### **Furrow irrigation system**

Furrow irrigation is the most widely used system for sugarcane in Queensland, and is favoured where topography and soil type permit. It has low capital costs, is simple to operate and is suitable for land with less than 3% slope [12]. Application efficiency can vary from 10% to 90% [10]. However, the more accepted range is 30% to 90% and efficiency can be improved by better management practice [12]. Where water is readily available at low cost, growers have little incentive to switch to alternative technologies. 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

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increased salinity in the Burdekin River Irrigation Area and on the Atherton Tableland in Queensland [10].

### **Centre pivot irrigation system**

Centre pivot is the most extensively used fully automatic overhead irrigation system. The irrigator rotates in a circle up to 1.6 km in diameter possibly covering 200 ha [12]. This system has the potential to deliver more than 90% application efficiency depending on slope of the land and wind conditions [10]. This technology is attracting increasing interest, particularly in areas of water scarcity. Advantages over furrow irrigation include easily varied application rates and a uniform distribution pattern, even under relatively windy conditions. Large areas can be irrigated with irrigator, at low cost for electricity and labour while liquid fertiliser can be applied during irrigation. A disadvantage is the relatively high initial capital cost (approximately \$2500/ha).

### **Drip irrigation system**

Drip or trickle irrigation systems have the potential to achieve more than 95% application efficiency. 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. The system operates at low pressure, allows small amounts of water to be applied to large areas, lends itself to automation and can be used for fertigation (application of liquid fertiliser). According to Thorburn et al. [13], studies published since the mid 1980s showed cane yield increases of 5% to 20% with evidence from a small number of studies indicating irrigation efficiency of 50% to 80%. Fertilizer input rates can be reduced due to more efficient application. A recent study [14] found that increased crop yield and sugar content were possible, with a 25% reduction in nitrogen input relative to the industry standard. Part of this gain arises from in-crop adjustment to nitrogen management to overcome problems such as loss of nitrogen in wet periods, compared to other systems where continual over-fertilisation may be a problem for the environment [14]. High installation cost (more than \$4000/ha) and low water quality which causes iron deposits in the pipes are the major barriers to adoption. In addition, a high level of management expertise is required.

### **The Burdekin delta irrigation study area**

The Burdekin River delta is located on the northeast coast of Queensland, close to wetlands, waterways, estuaries, and the Great Barrier Reef, approximately 90 km southeast of Townsville. It covers an area of about 850 km<sup>2</sup>, and together with the Haughton River – Barratta Creek system, is one of the largest alluvial aquifer systems in Australia. The groundwater system in the delta aquifer is considered to be unconfined (i.e. it has no impermeable overlying sediments) and therefore open to surface recharge. The area has a tropical climate and seasonal rainfall (two thirds falling during January to March), ranging between 250 mm and 2500 mm a year, with an average of about 1000 mm. Evaporation varies from 10 mm/day in November to 2.8 mm/day in June [15].

The Burdekin delta is predominantly used for sugarcane production, with some smaller areas under tropical fruits and vegetables and a small area where groundwater or soil quality are not suitable for sugarcane is used for cattle grazing. The delta is one of the few areas in Queensland where cane is grown under full irrigation and irrigation water use at 8 to 15 ML/ha is the highest of any cane growing area in Queensland, due to use of mainly furrow irrigation on highly permeable soils. On average, one ML is used to produce 3.5 tonnes of cane [10]. This inefficient use of irrigation water is believed to assist in maintenance of the aquifer. An artificial recharge scheme was introduced by establishing the North and South Burdekin Water Boards (NBWB and SBWB) in 1965 and 1966 respectively, to replenish the underground basin artificially. However, if growers were more efficient in use of water, then more water would be available in the aquifer for other crops or future irrigation use. Further, efficient irrigation practices will reduce pumping costs for growers and there will be less potential for leaching of nutrients and pesticides into the aquifer. Therefore, it is important to design and implement new and improved practices to ensure the long-term viability of irrigated agriculture in the area. In recent years, the water management boards have shifted their emphasis from groundwater recharge to more efficient water use [16].

### **Analytical framework and data collection**

For a comprehensive economic analysis, biophysical information (such as crop yield) is necessary and a series of crop simulations were performed using APSIM systems model [17] to estimate yield responses to applied irrigation for a range of soil types, water allocation, and application efficiencies varying from 30% to 90% for each of three irrigation methods. Simulations were run over a 20 year period of several crop cycles consisting of one plant crop followed by three ratoon crops. A sugar crop module, a soil water module, a soil nitrogen module and a surface residue module were linked to investigate yield responses to the applied irrigation [18]. The three soil types were representative of low, medium and high permeability soils in the Burdekin delta. Initially, it was assumed that a grower could use as much water as required to achieve maximum yield. However, as application rate increases, profitability will ultimately be reduced.

Because of the complex nature of calculations (such as groundwater-surface water proportion per hectare, differential surface water charges and progressive Australian taxation regime), a multi-period algebraic model (called CANEIRRI) has been developed using the GAMS (General Algebraic Modelling System) software package [19]. Annual farm cash surplus for alternative irrigation technologies were simulated over a 20-year planning horizon, and net present value computed. CANEIRRI consists of separate modules for furrow irrigation (with no new capital outlays), centre pivot (immediate capital investment during the fallow period) and trickle irrigation (capital investment spread equally over five years). Investment in trickle irrigation is timed to follow the four year crop and one year fallow cycle. Operating costs during the transition are based on proportion of area under trickle irrigation. Provision is made for deductions from income for capital investments on irrigation equipment, and for carrying forward business losses, for taxation purposes. No allowance is made for scrap value of the irrigation equipment at the end of 20 years. A summary of the algebraic equations of CANEIRRI is presented in Figure 1.

$$NPV_i = \sum_{t=1}^{20} (NPBT_{it} - TAX_{it}) * (1+r)^{-t} \quad \text{where,}$$

$$NPBT_{it} = TotR_{it} - FixC_i - IrOpC_{it} - CapO_{it} - TotElecC_{it} - \sum_{s=1}^3 GWatC_{ist}$$

$$- \sum_{s=1}^3 SWatC_{ist} - OVarC_{it} - DepnC_{it}$$

where,

$$TotR_{it} = \sum_{s=1}^3 (Yld_{it} * A_{ist}) * (P * 0.009 * (CCS - 4) + 0.578)$$

$$GWatC_{ist} = A_{ist} * GWP$$

$$SWatC_{ist} = \begin{cases} PSWat_{ist} * A_{ist} * SWP1 & \text{if } PSWat_{ist} \leq \alpha \\ \alpha * A_{ist} * SWP1 + (PSWat_{ist} - \alpha) * A_{ist} * SWP2 & \text{if } PSWat_{ist} > \alpha \end{cases}$$

$$DepnC_{it} = \begin{cases} CapO_{it} * \frac{1}{d} * TotA & \text{if } 1 \leq t \leq d \\ 0 & \text{otherwise} \end{cases}$$

and:

$$TAX_{it} = \begin{cases} TI_{it} * TRa & \text{if } TI_{it} \leq Ta \\ Ta * TRa + (TI_{it} - Ta) * TRb & \text{if } Ta < TI_{it} \leq Tb \\ Ta * TRa + (Tb - Ta) * TRb + (TI_{it} - Tb) * TRc & \text{if } Tb < TI_{it} \leq Tc \\ Ta * TRa + (Tb - Ta) * TRb + (Tc - Tb) * TRc + \\ (TI_{it} - Tc) * TRd & \text{if } Tc < TI_{it} \leq Td \\ Ta * TRa + (Tb - Ta) * TRb + (Tc - Tb) * TRc + \\ (Td - Tc) * TRd + (TI_{it} - Td) * TRe & \text{if } TI_{it} > Td \end{cases}$$

where

$$TI_{it} = \begin{cases} NPBT_{it} & \text{if } t = 1 \\ NPBT_{it} + TI_{i,t-1} & \text{if } t > 1 \text{ and } TI_{i,t-1} < 0 \\ NPBT_{it} & \text{if } t > 1 \text{ and } TI_{i,t-1} \geq 0 \end{cases}$$

i = irrigation system, t = planning horizon, s = soil type, NPV = net present value, NPBT = net profit before tax, TAX = tax paid, r = discount rate, TotR = total revenue, FixC = fixed costs, IrOpC = irrigation equipment operating cost, CapO = capital outlays, TotElecC = total electricity cost, GWatC = ground water cost, SWatC = surface water cost, OVarC = other variable costs, Yld = total farm yield, A = crop hectares, P = sugar price, CCS = percent sugar content in the cane, GWP = ground water price, PSWat = proportion of surface water, SWP1 = surface water price 1, SWP2 = surface water price 2,  $\alpha$  = water price threshold, DepnC = depreciation cost, 1/d = depreciation allowance, TotA = total farm area, TI = taxable income, TRa, TRb, TRc, TRd and TRe = marginal tax rates, Ta, Tb, Tc, Td, Te = lower limits of income brackets.

Figure 1: Algebraic relationships of the CANEIRRI model

This model has been used to evaluate and compare case study farms in the North and South Burdekin Water Board Areas. There are differences in the

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structure of groundwater charges between the two boards and in the threshold per-hectare volume of surface water for low-rate charges. Also, the proportions of groundwater and surface water used differ, due to differences in quality of groundwater and need to recharge the aquifer. In NBWB, the proportions of groundwater and surface water are 40% and 60%, while in case of SBWB, these proportions are 70% and 30% respectively. The average cane farm in the area serviced by NBWB uses less groundwater and more surface water than an average cane farm in SBWB area. Based on recent estimates [15], the proportions of three soil types on a 60 ha farm in the study area are assumed to be: low permeability 33%, medium permeability 56%, and high permeability 11%.

Average yields from each soil type and for each irrigation system obtained by using the APSIM biophysical simulation model were used in CANEIRRI economic model. Data about sugar production costs were obtained from a survey report compiled by the local BSES office [20] and from the local office of CANEGROWERS, while a fixed cost estimated by the ABARE Farm Survey [21] has been used in the analysis. The information about permanent (family) labour hours used and labour costs were estimated after discussion with growers and from the office of their association. Appropriate savings in each irrigation system due to reduction in fertiliser, herbicide and labour use have been made in the analysis. Data about sugar content were obtained from the local sugar mill and an average of the past 10 years was used. 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. The water charges and the threshold payment structure were obtained from material published by the water boards. The proportion of groundwater and surface water used on an average farm is different in each jurisdiction. Electricity charges were estimated on the basis of the appropriate electricity tariff and pumping costs for groundwater as well as surface water. The costs for the irrigation system were obtained from the local and regional irrigation systems and equipment supplier (Shanon Dempster, McCrackens Mareeba, *pers. comm.*). Parameters used in the analysis are set out in Table 1.

Table 1: Parameter values used in the analysis

<p>Farm size = 60 ha, sugar pool price = \$325/t, fixed costs = \$20000, NBWB groundwater charge = \$68.50, NBWB threshold for low-priced surface water = 8 ML, low-priced surface water = \$4.80/ML, high-priced surface water = \$22.20, SBWB groundwater charge = \$48.50, SBWB threshold for low-priced surface water = 4 ML, low-priced surface water = \$5.40/ML, high-priced surface water = \$13.67/ML, groundwater electricity charges = \$9.11/ML, surface water electricity charges = \$4/ML, volumetric water charges = \$39/ML, furrow capital outlays = \$0/ha, centre pivot capital outlays = \$2667/ha, trickle capital outlays = \$4200/ha, furrow operating cost = \$50/ha, centre pivot operating cost = \$8/ha, trickle operating cost = \$240/ha, percent sugar content (CCS) = 15, permanent labour cost = \$20/hour, harvesting contract charge = \$5.60/t, tractor cost = \$28.0/hour, planting cost = \$375/ha, fertiliser cost plant = \$250/ha, fertiliser cost ratoon = \$275/ha, herbicide cost plant = \$133/ha, herbicide cost ratoon = \$75/ha, insecticide cost plant and ratoon = \$0/ha, permanent labour plant = 40 hours, permanent labour ratoon = 25 hours, Australian marginal tax rates = 0, 17%, 30%, 42% and 47%, Australian taxation limits = \$6000, \$20000, \$50000, \$60000 and &gt;\$60000, planning horizon = 20 years, discount rate = 7%.</p>
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## Results and discussions

Results from the preliminary analyses for NBWB and SBWB case study farms are presented in Table 2 along with volumetric water charging policy option. These results indicate that NPVs of the southern area farm are higher than for the northern area farm because the relatively greater input of less expensive groundwater. The ranking by NPV of the three irrigation systems is the same in each district. The furrow system has the highest NPV followed by centre pivot then trickle irrigation system. In SBWB, a positive taxable income is achieved in Year 5 with centre pivot irrigation, but not till Year 9 with the trickle irrigation system. When volumetric water charges are used instead of area-based groundwater and differential surface water charges, the rankings of technologies changes and centre pivot has the highest NPV followed by furrow then trickle, but the NPV for trickle irrigation becomes negative (-\$94,785). Under the volumetric water charging option, the overall NPVs for each irrigation system are lower than the NPVs for area-based water charges.

Table 2: Net present values for three irrigation technologies, NBWB and SBWB and volumetric water charge option (\$1000)

Irrigation system	NBWB	SBWB	Volumetric water charge option
Furrow	399	446	98
Centre Pivot	321	348	111
Trickle	161	194	-94

The values for key parameters – discount rate, sugar prices, capital investment costs, farm ownership arrangement, and other important variables – have been varied systematically to examine their effect on the rankings of the three systems. Discount rates used are 5%, 7% and 9%. The price of sugarcane and capital cost of centre pivot and trickle systems have been altered by  $\pm 20\%$  from base values. Only results for the SBWB farm sensitivity analysis are reported. The rankings of these irrigation options do not change by altering values of any of these parameters. The NPV of centre pivot only becomes higher than that for furrow irrigation when there is more than 40% reduction in its capital cost. Similarly, the NPV of the trickle option only becomes higher than furrow when its capital cost is reduced by 80%. This level of reduction in these capital outlays is not likely to happen. Switching from sole owner to partnership increases after-tax income, but does not change the NPV ranking of the irrigation options. When proportion of high permeability soil is altered to 100 %, there is change in the rankings of the irrigation options. Centre Pivot becomes the best option with highest NPV (\$325,665) followed by furrow (\$261,508) then trickle (\$111,481). These results indicate that the rankings are sensitive to the soil proportion.

## Conclusions and policy implications

An integrated bioeconomic modelling approach has been used to compare irrigation technologies for a sugarcane farm in northern and southern areas of the Burdekin delta where differential charges, volumetric for surface water and area-based groundwater charges, are common practice. The furrow irrigation option is the most attractive for the growers even though it is a less efficient irrigation option. However, when volumetric water charges are used in the analysis as a potential policy option, centre pivot irrigation becomes the best option. The

change in values for most of the key parameters does not change the rankings and furrow remains the best option. However, when soil type proportion is altered to high permeable soil, rankings change and CP becomes the best option followed by furrow then trickle. These results indicate that low water charges are the major incentive for cane growers to use the existing furrow irrigation system which is less efficient but also less costly for them so there is little incentive to switch to more efficient alternative irrigation technologies.

The economic information so generated can be used to inform farmers about the likely long-term consequences of investment decisions involving modern irrigation technology. The model can be easily adapted to analyse the impact of farm size as the costs and revenues used in the model are based on area estimates. The model could also be used to aid natural resource managers and regulatory agencies in examining the impact of water charges on growers' incomes. The framework provides a useful means for examining various scenarios and testing policy options that affect either input costs or farm incomes of growers. However, a number of limitations are recognized for the CANEIRRI model. The model incorporates data about crop yield and volume of water exogenously and selective figures for an agronomic optimum were used without determining economically optimal yield and irrigation level. Further studies can be carried out once experimental results are available about the relationship between level of water applied and crop yield.

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