DAM EA$Y

A Framework for Assessing the Costs and Benefits of On-Farm Storage Based Sugarcane Production Systems

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Abstract

Sugarcane farmers in many districts are considering on-farm water storages (OFWS's) as a means of countering ongoing water shortages. OFWS's are attractive because they can be used to capture runoff and tailwater, and for the temporary storage of surplus water from other irrigation sources (eg allocation, out of allocation, water harvesting etc), thereby providing increased flexibility in managing limited water supplies. The decision to invest in such storages is, however, complex and multi-facetted, requiring assessment of a range of biophysical, economic, legislative and social factors. Computer-based simulation models can potentially capture many of these factors and their interactions, and hence, can play a useful decision support role. In this paper, we describe and demonstrate a new software package (Dam Ea$y) that couples biophysical and economic modelling tools, in a way that enables analysis of various scenarios regarding investment in OFWS, and the likely benefits and costs of such investments.

Introduction

Annual sugarcane production in the Bundaberg region is often limited by the availability of sufficient irrigation water. While the deficit between crop demand and effective rainfall for sugarcane crops in this region is approximately 7.8 ML/ha (at 85 % irrigation application efficiency) (Willcox *et al.*, 1997), the average allocation per grower is less than 4 ML/assigned ha. Consequently, local farmers are turning to on-farm water storage (OFWS) structures to help address some of their water shortage problems. The decision to invest in such storages, is however, complex and multi-facetted, requiring assessment of a range of biophysical, economic and social factors, and the interactions within and between these domains. Within the biophysical arena, there are complex interactions between farm management, crop, climate, soil type and catchment related factors. Economic feasibility is sensitive to a range of factors including the cost of installation and year to year fluctuations in yield and sugar price. Computer simulation models can capture many of these processes and their interactions and can provide a useful decision support capability for farmers and advisers. With this in mind, a software package was developed, called Dam Ea$y, that couples biophysical and economic modelling tools in a way that enables analysis of various scenarios regarding investment in OFWS, and the likely benefits and costs of such investments.

This paper describes the various components of the Dam Ea$y package and demonstrates its capability via a case study in the Bundaberg region, developed with the assistance of a group of cane farmers and advisors. While the package has been customised to meet the specific needs of farmers in the Bundaberg production region, it is generic in nature and could be readily adapted to other sugarcane production regions.

Dam Ea$y structure

General

Dam Ea$y consists of three main components; a database of pre-run biophysical model output for a range of OFWS-based production systems, a 'real-time' economic model, and an interface through which the operator interacts with the package (Figure 1). Production systems of interest to the operator are 'constructed' within Dam Ea$y by selecting from a discrete number of variable settings (eg irrigation area, OFWS capacity etc) contained in drop-down menus within the user interface. This construction process serves to identify specific system designs held within the biophysical database. The operator also sets a number of economic variables (eg sugar price, interest rates etc), which, in conjunction with biophysical data from the database, are fed into the 'real-time' economic model. The package offers a wide range of biophysical and economic outputs and different types of graphical representation for subsequent interpretation and analysis. Various preset and customised forms of reporting are available to the user.

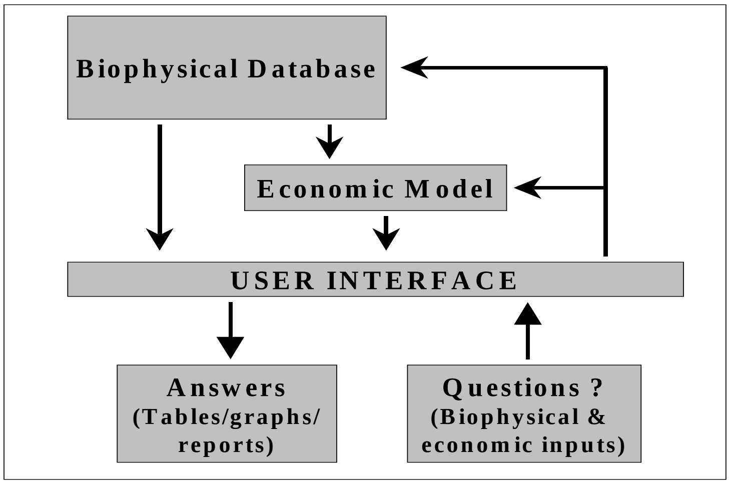

Figure 1: Structure of Dam Ea$y

Biophysical database

The biophysical database, which is currently in a prototype form, was created using the systems model, APSIM (Agricultural Production Systems sIMulator; McCown *et al*. 1996) and covers in excess of 70 000 system designs representing current practice in the Bundaberg region, as well as alternative designs for the purpose of scenario or 'what if' analyses. Separate model runs were conducted for each system design over a 40-year period (using historical climate files), to capture responses to season-to-season climate variability, and to enable short to medium-term investment analysis.

APSIM combines modules describing the specific processes within the system under investigation. For the purposes of Dam Ea$y, the sugar crop module APSIM-Sugarcane (Keating *et al.,* 1999) was configured to enable simulation of a sugarcane production system irrigated using water from any combination of OFWS, out of allocation (OOA), or scheme allocation (Figure 2).

Out of allocation water. OOA water is available for irrigation when the daily flow rate of the scheme river under consideration exceeds a specified maximum, for a specified number of days. When OOA water is available and not being used for irrigation purposes, it is used to top up the OFWS (if present).

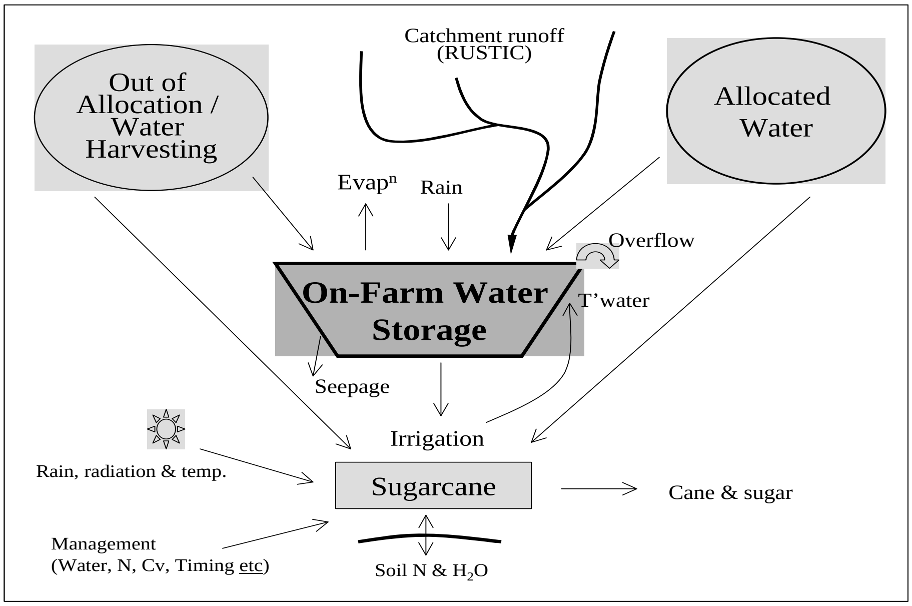

Figure 2: Framework of biophysical model.

Allocation water. Both the volume of water allocated from an irrigation scheme (ML/ha) and the period over which this allocation is available, are nominated by the model user. In order to minimise the volume of 'carry-over' water, the model will transfer unused allocation water to the OFWS (if present) during a user-defined period at the end of the allocation period.

On-farm water storage. Daily calculation of the stored water volume (V_{ofs}, Equation 1) takes into account the various elements of the storage water balance. Inflows include water sourced from catchment runoff (Ru), direct rainfall capture (R_{ofs}), recycled tailwater (T) and, allocation (A_t) and OOA (O_t) water transferred from the scheme to the storage. Outflows are from surface evaporation (E_{ofs}), irrigation of caneland (I), seepage losses (S) and overflow (O_v). The mass balance can be expressed in equation form as:

$$V_{ofs} = (Ru + R_{ofs} + T + A_t + O_t) - (E_{ofs} + I + S + O_v) \qquad (1)$$

In the absence of measured, site-specific data, daily catchment runoff is estimated using the QDPI model, RUSTIC (Runoff, Storage and Irrigation Calculator) (QDPI, 1994). Direct rainfall capture by the storage is based on daily rainfall data for the site in question and the maximum surface area of the storage. The storage is assumed to be trapezoid in shape with the evaporative surface area at any time estimated from regression equations describing the volume by surface area relationship of the storage. Seepage losses are estimated using algorithms from Horton & Jobling (1992) and depend on the head of water in the storage and the permeability (user-defined) of the soil underlying the storage. Overflow occurs when the capacity of the storage is exceeded and is reported variously as the seasonal overflow volume, the number of overflow events of one or more days in duration, and the total number of days that the storage was overflowing.

Irrigation rules. The order in which water sources are used is pre-set. On any given day, OOA is the irrigation source of first choice, followed by OFWS water and then allocated water. OFWS water is used in preference to allocated water so as to minimise evaporative losses from the storage.

Aside from the order of water usage, the model provides for substantial flexibility in irrigation management. The operator can set the following:

- Deficit to irrigate (mm)
- Applied irrigation amount (mm)
- Efficiency of irrigation application (%)
- Irrigated area (ha)
- Irrigation cycle length (days)
- Drying–off period (days)
- Allocation to OFWS transfer period (days)

Other system design options. By establishing this model within the larger framework of APSIM, the simulation capability can be extended to encompass the broader sugarcane production system. Within this framework, the operator can specify a whole range of other crop management practices, on different soil types and across a range of locations.

Economic model

The economic model provides the operator with an ability to evaluate OFWS and irrigation investment options based on the simulated crop and water storage yields from the biophysical database. The economic model has been developed from the spreadsheet model of Shuurs and Wegener (1999), which incorporates the capital and operating costs associated with five different types of irrigation delivery systems and for an OFWS. The biophysical database supplies crop yield and irrigation source data (ie allocation, OOA and OFWS) associated with selected OFWS system designs. Additional physical and financial parameters characterising the farm must also specified by the operator at the Dam Ea$y user interface. These data include farm size, cane area lost to the OFWS structure, scheme allocation, scheme allocation water price, out-of-allocation water price, total OFWS set-up costs, reticulation system and associated operating costs, tax regime, whether using existing or borrowed funds to finance investment, discount rate and other fixed and variable cane production costs. Default data are supplied for many of these parameters.

The analysis considers the irrigation investment in the context of a farm business subject to income tax, and eligible to claim deductions for certain irrigation expenditure. The Australian Income Tax Assessment Act contains certain provisions to encourage the development of water resources and investment in irrigation infrastructure. The government has established these provisions to help stabilise income from primary production, facilitate self-reliance and hence reduce the need for, and cost of, government support during drought. Relevant aspects of the current Act have been incorporated into the economic model. However, the model will need to be modified to correspond with new taxation provisions associated with the introduction of the GST on July 1, 2000.

Dam Ea$y financial output can be presented in several ways according to the information needs of the operator. A key output is a discounted cash flow analysis produced over a 20-year time frame to reflect what is considered to be a reasonable investment horizon for a cane grower, and to coincide with the expected life of much of the irrigation equipment. Financial performance of selected investment options are also summarised using measures such as net present value, internal rate of return and break-even values.

Case Study

A case study was conducted to investigate the costs and benefits of investing in an OFWS for a sugarcane farmer in the Bundaberg district, currently operating with access to a small scheme allocation and OOA water only (hereafter referred to as the 'benchmark' design). "Dam Ea$y" originated from our interactions with a client group at Bundaberg, called the "Bundaberg On-Farm Water Storage Working Group", which recognised the valuable applications of the research team's capability in assisting decisions about OFWS investment. Comprising growers and advisers, the group already had an established interest in encouraging adoption of OFWS's in the district and was supportive of seeing the research team's capability applied to their interests in OFWS. The group agreed to provide on-going interaction with the research team and, through this process, defined the questions that Dam Ea$y might help to answer and then nominated case study parameters that members felt were relevant to local operations.

Three OFWS capacities were considered, namely 10, 30 and 50 ML. Rainfed and fully irrigated ('unlimited') designs were also simulated for comparison purposes. Table 1 summarises the key biophysical characteristics for each design. A representative cropping sequence for Bundaberg was used. OOA water was deemed to be available when the flow rate over the Burnett River Barrage exceeded 2400ML/day for a minimum of seven days. Each design was simulated over a 40-year period, using Bundaberg GPO weather station data from 1957 to 1997.

Table 1: Key biophysical characteristics.

Variable	Rainfed	Fully irrigated	Benchmark ± OFWS
Allocation (ML/ha)	0	15	3
Access to OOA	No	No	Yes
Catchment size (ha)	0	0	150
Capacity of OFWS (ML)	0	0	10,30,50
Assigned irrigation area (ha)	0	50	50
Irrigation efficiency (%)	0	75	75
Soil Type	Clay	Clay	Clay
PASW (mm to 90cm)	126	126	126
Catchment soil type	N/A	N/A	Clay
Catchment cover type	N/A	N/A	'Crop'
Catchment condition	N/A	N/A	'Good'
Irrigation cycle length (days)	0	10	10
Allocation duration	N/A	July 1–June 30	July 1–June 30
Carry-over	N/A	Not available	Not available
Transfer pumping rate (ML/day)	N/A	N/A	1% of alloc'n
Alloc'n to OFWS transfer period (days)	N/A	N/A	45 days

Climate data	Bundaberg	Bundaberg	Bundaberg
Cultivar	Q124	Q124	Q124
N fertiliser (kg N/ha)	Unlimited	Unlimited	Unlimited
Drying-off (days)	N/A	45	45

Table 2 lists the key economic parameter settings for the representative farm used in the case study. It is assumed that the OFWS was constructed without loss of production area. For this specific example, OFWS construction costs (ie earthworks, underground costs and pumps) are assumed to be financed with the grower's own funds. Borrowed funds repayments are therefore not included in the net income calculation.

Table 2: Key economic model parameter settings.

Parameter	**Setting**
OFWS construction cost	\$2500/ML (10ML), \$2000/ML (30ML), \$1500/ML (50ML)
OFWS pump and underground works costs	\$20000
Pumping cost (scheme to OFWS)	\$25/ML
Water charges[1]	\$38.76/ML
Cost of installing reticulation equipment[2]	Nil
Sugar price	\$300/t (assumed constant)
CCS	14.3
Discount rate (opportunity cost of capital)	6%
Operating cost for reticulation[3]	\$41/ML
Other variable production costs[4]	\$712/ha
Fixed production costs[5]	\$14 750

[1] Current scheme water charges for allocation and OOA (Passmore, 1999).
[2] An existing winch reticulation scheme is assumed.
[3] Includes repairs and electricity costs.
[4] Includes other input costs such as fertiliser, cultivation costs etc.
[5] Fixed costs are also known as 'overheads' and include insurance, registrations etc.

Results & discussion

Biophysical

Figure 3 illustrates the partitioning of total applied irrigation across the three irrigation sources for the various system designs, averaged over the 40-year simulation period. In the absence of an OFWS ('benchmark' in Figure 3), irrigation from the allocation and OOA sources (totalling 195 ML) met ~50% of the irrigation demand under unlimited conditions (393 ML). The addition of OFWS's of 10 ML, 30 ML and 50 ML capacity increased this irrigation reliability to 60%, 72% and 81% respectively. This improvement in reliability with increased storage capacity can be attributed to gains in storage efficiency, as more of the available runoff is held by the OFWS. That is, of the 402 ML (40-year average) of runoff generated by the catchment, the proportion lost as overflow decreased from 92% for the 10 ML storage, to 72% for the 50 ML storage. Storage size also influenced the efficiency of allocation usage. Given the preference for irrigating with OFWS water before allocated water, we would expect a decline in allocation irrigation with increasing OFWS size. Indeed, allocation irrigation declined from 150 ML in the absence of an OFWS, to 143 ML with a 50 ML OFWS. The modest nature of this decline reflects the fact that the irrigation supply from OFWS and out of allocation sources for each of the OFWS based designs, was substantially less than the irrigation requirement under unlimited conditions. Hence, most of the nominal allocation was required in each design.

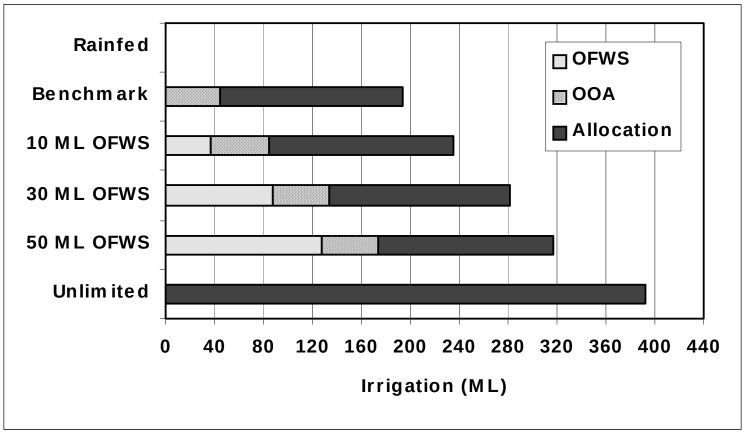

Figure 3: The partitioning of total applied irrigation (averaged over 40 years) across the three irrigation sources, for the benchmark design (OFWS free), rainfed, fully irrigated, and systems with access to OFWS's of varying capacity (0-50 ML).

Figure 4 depicts 40-year cumulative distribution frequency (CDF) plots of cane fresh weight for each of the six system designs. This presentation format allows risk to be considered in a quantifiable sense. For example, a grower assessing the 10ML storage can identify that 25% of the yields achieved in the 40-year simulation period fell below 55 t/ha. As expected, cane fresh weight increased with greater availability to irrigation. Under rainfed production, seasonal yields ranged from 23 t/ha to 137 t/ha with a median yield of 81 t/ha (corresponding to a cumulative probability of 0.5). Under fully irrigated conditions, yield ranged from 126 t/ha to 183 t/ha with a median yield of 160 t/ha. The reduction in the yield range between these two extremes demonstrates the impact of irrigation in reducing the effects of season-to-season rainfall variability. Interestingly, the yield range for the OFWS-based systems was relatively insensitive to storage size. This reflects the fact that in low rainfall years, when yield tends to be small, catchment runoff will also be small and the larger storages will be under-utilised. At the other extreme, large yields will tend to occur in high rainfall years, when the efficiency of all storages is likely to be reduced and the irrigation demand will be low. The diminishing gains in median yield (corresponding to a cumulative probability of 0.5) with increasing storage size, reflect the diminishing gains in irrigation reliability as irrigation supply approaches potential demand (under full irrigation).

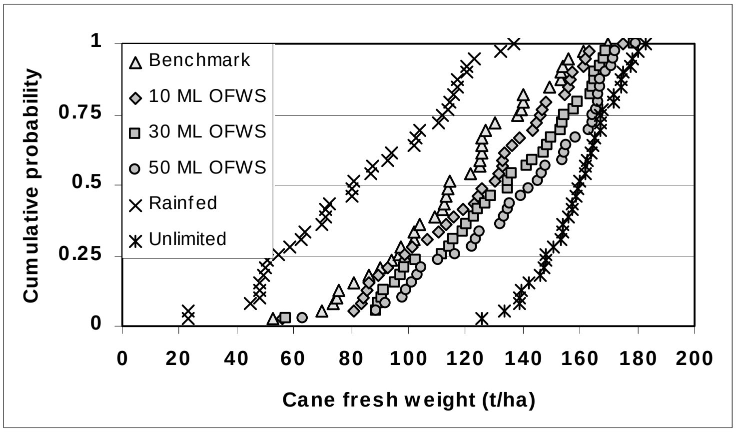

Figure 4: Cumulative distribution frequency plots of seasonal cane fresh weight (t/ha) over the 40 years of the simulation period for the benchmark (OFWS free), rainfed, fully irrigated, and designs with access to OFWS's of varying capacity (0-50 ML).

Economic

Net present value. A grower/advisor can use net present value (NPV) to assess the total net benefit of an OFWS over the entire 20-year investment period. The NPV calculation sums the discounted, additional costs and benefits involved in the OFWS investment compared to the 'do nothing' (<u>ie</u> benchmark) design. For a cane grower, the investment in an OFWS is acceptable when, subject to budget constraints and other relevant conditions, the NPV of benefits is positive.

Because the discounting process 'erodes' the value of benefits received in the future, the timing of the OFWS investment will impact on the NPV. For example, an OFWS investment coinciding with a sequence of 'good' years followed by 'bad' years will have a higher NPV than if the sequence of good and bad years was reversed. Dam Ea$y allows for the assessment of risk associated with the timing of the investment. The biophysical database contains simulated crop and storage yields over 40 years, enabling a distribution of NPV's to be generated by calculating NPV's of OFWS investments with different starting years. Using forty years of data, it was possible to calculate 20 NPV's for each of the three OFWS-based systems for this Bundaberg case study. The results are presented as cumulative distribution frequency plots in Figure 5.

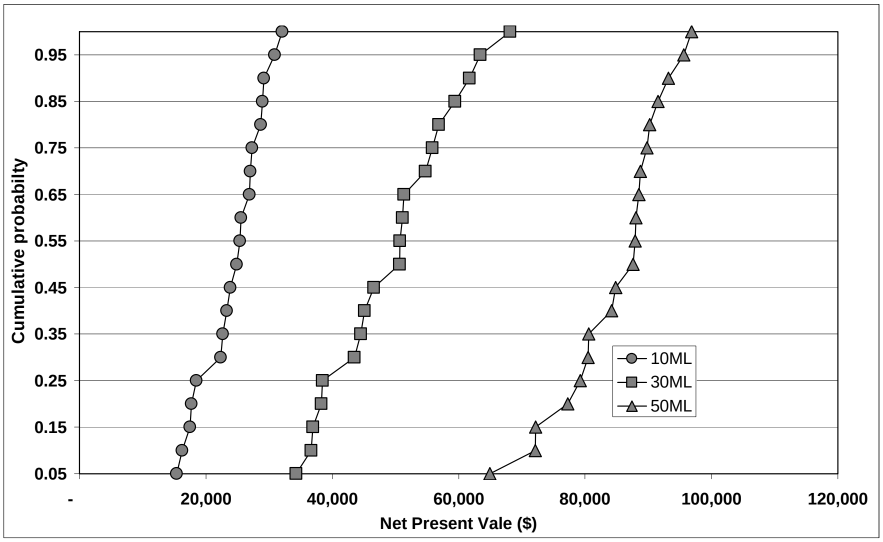

Figure 5: Cumulative distribution frequency plot of Net Present Value ($) for the three OFWS-based systems with a sugar price of $300/t.

All storage capacities have positive NPV's and can be viewed as positive investments based on the variables specified in the analysis. The 50 ML storage was associated with the most NPV variability. However, as NPV's were always higher than those for other storage capacities, this appears to be the best investment.

Table 3: NPVs associated with three quartiles from CDF plots for three sugar prices ($250/t, $300/t, $350/t).

	$250/t			**$300/t**			**$350/t**		
Percentile	**10ML**	**30ML**	**50ML**	**10ML**	**30ML**	**50ML**	**10ML**	**30ML**	**50ML**
25	7,204	15,951	47,447	18,477	38,471	79,253	27,865	55,999	104,519
50	12,387	25,812	56,075	24,876	50,662	87,607	33,952	68,797	112,098
75	14,714	31,520	57,218	27,293	55,859	89,818	37,227	73,775	114,962

NPV's for each of the OFWS-based designs, using a sugar price of $300/t and corresponding to 25, 50 and 75% probabilities, are shown in Table 3. NPV's associated with a lower ($250/t) and higher ($350/t) sugar price are also included. Falling sugar price significantly depresses the range of NPV's achievable. Such sensitivity testing of the investment is particularly pertinent in the current period of low sugar prices facing Australian sugar producers.

After tax income flow. NPV is an appropriate measure to summarise financial performance over the entire duration of an investment. It does not, however, provide information about year-to-year income variability within the investment period. An investment with a positive NPV could be rejected if cash flow variability is considered too high. The Dam Ea$y package allows operators to compare annual cash flows for various OFWS designs with OFWS-free designs.

Annual after-tax net income for the three OFWS-based designs and the benchmark design (OFWS-free) are displayed over the 20-year simulation period from 1977-1996 in Figure 6. These cash flows commence in the year after the purchase of the storage. This particular investment period generated the highest NPV's of$32 091, $68 145and $96 884 for the 10 ML, 30 ML and 50 ML OFWS-based systems, respectively.

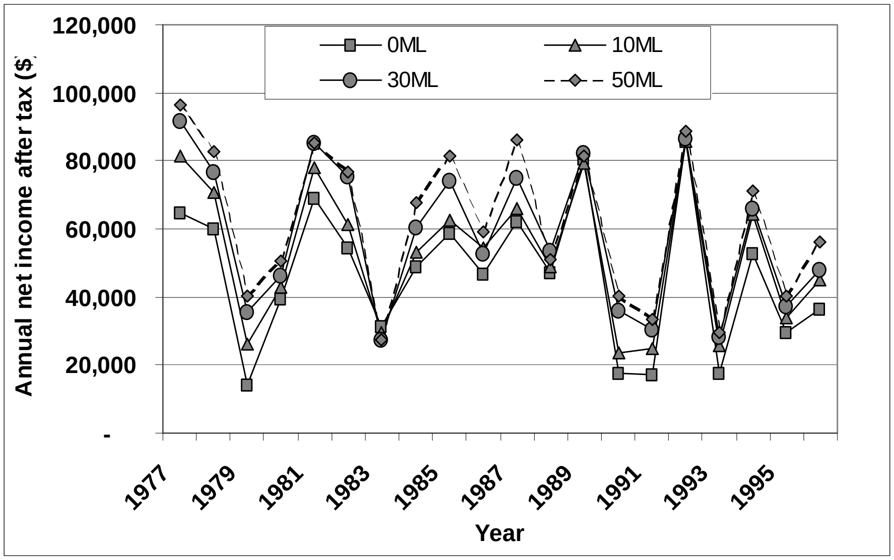

Figure 6. After-tax farm net income ($) for the three OFWS-based designs (10 ML, 30 ML, 50 ML) and the benchmark design (OFWS-free) displayed over the 20-year simulation period from 1977-1996 (sugar price $300/t).

Net incomes were generally lowest under the OFWS-free system and highest for the 50 ML OFWS system. The relative insensitivity to OFWS capacity in 1983, 1989 and 1992 can be attributed to high rainfall in these years and hence a reduced reliance on irrigation.

Conclusions

Increasing demands for water from all sectors of the economy means that irrigated agriculture has to develop more efficient ways of using the water that is made available. This has lead to sugarcane farmers considering on-farm water storage's as a means of capturing as much water as they can and in providing them with increased options for managing limited water supplies. In deciding whether or not to invest in an OFWS, farmers and their advisors are confronted with a plethora of questions relating to the biophysical, management and economic implications and the interactions across these domains. Decisions are further complicated by year-to-year climate fluctuations, and hence the yield distribution over time. This coupled with temporal variability in commodity prices has a strong influence on the year-to-year return on OFWS investment. The adoption of a modelling approach such as that employed in Dam Ea$y offers a means of capturing and interpreting some of this complexity. The inclusion of a database comprised of pre-run biophysical simulation output for a large range of production system designs, linked directly to an economic model in which there is flexibility in the setting of key economic variables, provides a rapid means of analysing a large range of different scenarios. Running the biophysical simulations over a 40-year period using historical climate data, captures the influence of temporal climatic variability on yield and the associated medium-term investment implications.

The case study analysis reported in this paper demonstrated a small part of the proposed Dam Ea$y capability. It is not intended that the results of the case study be used to form industry recommendations on best options for OFWS investment in the Bundaberg district. Rather, the Dam Ea$y financial output, characterised by substantial climatic and sugar price driven income variation for even a single OFWS design, supports the conclusion that generalised recommendations are not appropriate. Our industry partners in this research, the On Farm Water Storage Users Group, have also made this assessment and are supportive of the research approach adopted to assess this problem. Dam Ea$y, as a research process and as a product, is complex. It combines complex models, a team of researchers with diverse disciplinary backgrounds and a client group with little or no initial familiarity with modelling concepts. With this in mind, we are sensitive to the possibilities of problems concerning acceptance of decision support tools and recognise the need to carefully consider our research approach if we are to ensure that Dam Ea$y is valued and used by our clients. An evaluation of Dam Ea$y research product and process is underway as part of a PhD study into the benefits of collaborative research[1]. Our vision for Dam Ea$y is not concerned with providing the ‘ultimate solution’ to cane farmers but, rather, serving as a powerful tool to assist individual operators make their own assessment of what investment option would best suit their particular farm characteristics, attitudes to risk and other personal preferences.

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[1] The PhD study is being conducted by Ms Tracy Bramwell, School of Natural and Rural Systems Management, University of Queensland. It is funded by the CRC for Sustainable Sugar Production.

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