DECISION SUPPORT PROGRAMMES FOR ASSESSING THE IMPACT OF IRRIGATED SUGARCANE ON WATER RESOURCES AND PROFITABILITY

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Abstract

Water is a scarce resource in many areas of South Africa, where sugarcane competes with other crops as well as industrial and domestic water users. Legislation and economic forces are placing renewed focus on water use efficiency and both dryland growers and sugar farmers who irrigate are frequently required to defend their allocation of water.

Decision support programmes (DSPs) can help interpret the impact of sugarcane production and irrigation strategies on water resources and profitability. This paper illustrates the use of a number of DSP's, developed at, or used by the SA Sugar Association Experiment Station (SASEX), in a case study for the Mhlathuze catchment.

Introduction

Sugarcane is a major land use in KwaZulu-Natal and Mpumalanga and competes with other crops, as well as industrial and domestic water users, for water resources. Approximately 420 000 ha is currently under sugarcane in South Africa, of which approximately 21% is irrigated, primarily supplying the northern mills of Malelane, Komati, Pongola, Umfolosi and Felixton. In the northern areas where annual rainfall is low (600 to 700 mm), and class A-pan evaporation high (1900 to 2000 mm), large volumes of irrigation water are required by the crop for maximum production, typically of the order of 10 Ml/ha. Elsewhere irrigation supplements rainfall and in many parts of the industry where annual rainfall is moderate (800 to 1000mm) and class A-pan evaporation low (1500 to 1800 mm) volumes of irrigation water required to maximize production are small (5 to 8,5 Ml/ha). The decision on what type of irrigation system to invest in and the appropriate irrigation strategy to be used is a complex one, linked closely to economic return, and influenced by local climate, soils and water availability.

Recent legislation is changing the framework in which irrigation planning and operating decisions are made. Decisions are becoming more complex as new controls on water management are imposed and water becomes more scarce and expensive. This is particularly true in catchments where there is acute competition for the water resource. Decision support programmes (DSP's) can play an important role in assisting growers to make correct decisions and inform government and planning agencies of local water requirements and impacts. A number of DSPs have been developed or are being used at SASEX for this purpose, including:

- IRRIECON, an irrigation economics programme used to assess economic viability under varying irrigation strategies, and CANESIM, a crop model used to assess crop response under different irrigation strategies.
- Geographic Information Systems (GIS) used for spatial interpretation of trends in irrigation economics and irrigation requirements.
- ACRU, an agrohydrological model developed at Natal University (Schulze, 1995) and database query programs (ACRUQuery and Genscn) used to assess, for example, the impact of dryland and irrigated sugarcane on water resources.

This paper illustrates the use of these DSPs for irrigation planning in the Mhlathuze catchment, situated in the Zululand North region of KwaZulu Natal, where the Department of Water Affairs and Forestry (DWAF), as well as local water authorities, are currently investigating water allocations.

Mhlathuze catchment

The Mhlathuze catchment is located inland of Richards Bay and has a catchment area of 4210 km^2 (Figure 1). There is acute competition for water between industry and domestic users, located primarily in the Richards Bay/Empangeni area, irrigated and dryland agriculture, commercial forestry and the river and estuarine ecological water requirements. A summary of water use by the various sectors is given in Table 1 (Steyl *et al*., 2000)

While concern has been expressed at certain assumptions made in and therefore the accuracy of hydrological calculations, the table indicates that demand exceeds the current system yield by 32,4 million m^3/year. The dominant agricultural practices in the area are afforestation (55 000 ha), dryland cane (25 500 ha), irrigated cane (12 000 ha), irrigated citrus and other crops (2 200 ha).

Table 1. Sectoral water use in Mhlathuze catchment (after Steyl *et al*., 2000).

Land / water user	Impact on system water yield (million m^3/year)
Dryland forestry	12.7**
Irrigation allocation	176.5
Urban domestic and light industrial	32.4
Heavy industry	74.4
Rural domestic and stock watering	3.1
Ecological reserve	16.0
Total	**302.4**
Current system yield	270.0
Deficit	32.4

** accounted for in system yield calculation

Irrigated agriculture is by far the largest water user and has thus been targeted for re-appraisal of current water allocations, especially since irrigation is regarded as an 'inefficient' user of water when compared with manufacturing and industry.

Recommendations made by authorities to effect water savings in the agricultural sector need to account for the impact of decisions on grower long-term profitability. DSPs can provide useful guidance to decision makers and policy makers to answer questions such as:

1. Why irrigate - is it profitable to farm under dryland conditions?
2. Why not change to more efficient irrigation systems?
3. Are current water allocations fair, or do they exceed crop water requirements?
4. Is it possible to make water savings through better scheduling?
5. Would reducing the area under dryland sugarcane be an option to conserve water?

These questions will be explored for the Mhlathuze catchment using the DSPs described below.

Decision Support Programmes for water management decisions

Assessing the economics of irrigation.

An irrigation economics computer program (IRRIECON) has been developed at SASEX to help assess the economic viability of sugarcane irrigation options (Singels *et al*., 1999). Costs, including irrigation fixed and variable costs, harvesting and haulage costs and crop establishment and ratoon management costs are included in the analysis. Estimates of sugarcane yield and irrigation application, used in the economic assessment, are derived from the CANESIM model, formerly named IRRICANE (Singels *et al*., 1998), a water balance model using daily rainfall and derived crop evapotranspiration data. Combining CANESIM estimates of yield and irrigation application with the economic analysis of IRRIECON, one is able to assess the viability of different irrigation options.

Spatial trends in irrigation profitability

Geographic information systems (GIS) are useful tools to store, manipulate and analyse data and produce maps to interpret spatial trends. Application of GIS in the SA sugar industry has been described by (Gers *et al*., 1999b; Wallace, 1996; Platford, 1990). In the context of sugarcane irrigation, GIS is a useful tool to map climate patterns and trends in dryland and irrigated yield, irrigation water requirements, as well as irrigation economics, as described by Gers and Schmidt (1999a).

Assessing the hydrological impact of irrigated and dryland cane

The hydrological impact of any land use is currently a major area of focus in terms of the National Water Act (Act 36 of 1998). Research catchments located at LaMercy have provided measurements over 22 years, of the impact of sugarcane management practices on water resources (Schmidt *et al*., 1998). An internationally recognized model (ACRU), developed by the School of Bioresource Engineering and Environmental Hydrology of Natal University (Schulze, 1995) has been verified against research catchment data and shown to give good representation of sugarcane runoff response (Schmidt *et al*., 1998). A regional simulation analysis of hydrological and yield response of sugarcane under dryland and irrigated conditions was completed, using the ACRU model, for all sugarcane catchments (Schulze *et al.,* 1999). A database and query programme (ACRUQuery) has been developed to evaluate the hydrological impact of irrigated and dryland sugarcane and other land uses, as simulated by the ACRU model. A graphical visualization tool (Genscn) can also be used to assess hydrological trends through time. These DSPs provide valuable tools to inform stakeholders of the hydrological impacts of sugarcane.

Using DSPs for water management decisions in the Mhlathuze catchment

Why irrigate - Is it profitable to farm under dryland conditions?

Approximately 40% of sugarcane in the Mhlathuze catchment is irrigated. Irrigation is essential in the rainshadow areas of Nkwaleni and Heatonville and in other areas where poor soils

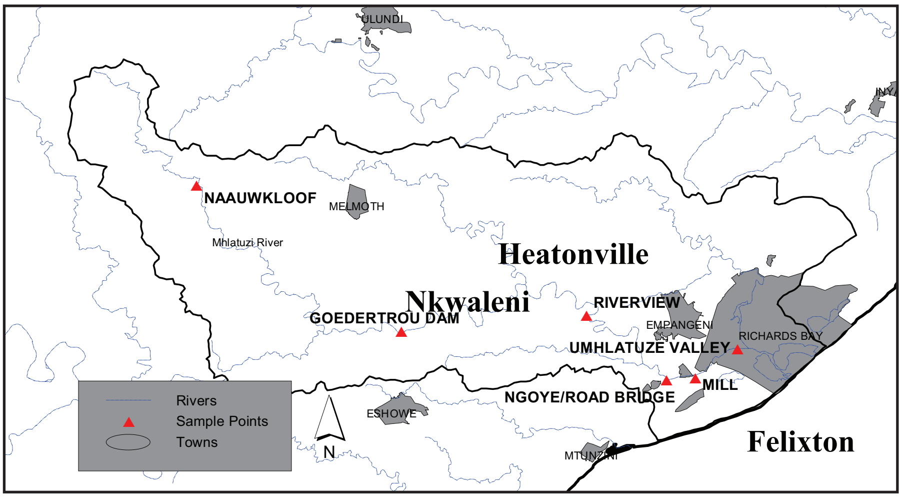

Figure 1. Mhlathuze catchment.

provide limited soil water storage. Table 2 gives estimated annual yields for two sites, Nkwaleni and Felixton. Mean annual rainfall and sugarcane potential evapotranspiration (PET) are also given for these sites. Results are based on the CANESIM model, using long record daily climate data, and are given for two soil conditions, and both irrigated and dryland conditions. Good soils represent soils with a total available water (TAW) content of 150 mm and poor soils a TAW of 60 mm. Irrigated yield and irrigation water requirement will vary depending on irrigation system and strategy. In this example it is assumed that the irrigation system is an overhead sprinkler system applying 25 mm to the crop every seven days, when the soil can accept the water. Yield figures given in brackets represent the best and worst yields during the period of simulation. A management factor of 80% was used to reduce simulated 'potential' yields to that which would be expected on a commercial estate.

Table 2 illustrates the different climate regimes at the two sites. The yield increase expected with irrigation at Nkwaleni is much higher than that at Felixton. The low dryland yields at Nkwaleni and high between-year variability make dryland production unviable.

The economics of changing from dryland production to irrigated production can be assessed using the IRRIECON DSP previously described. Economics will vary markedly depending on grower specifics and the example given below is intended only to illustrate broad trends. The analysis is based on the approach described by Schmidt (1996) and compares annual yield improvement under irrigation, and hence increased revenue, against the annual costs of purchasing and operating the irrigation system. Table 3 gives typical costs used for illustrative purposes in this analysis.

IRRIECON performs an economic assessment for each year over a selected period, typically 20 years or more. Estimates of sugarcane yield and irrigation water requirement are based on the CANESIM model with adjustments made to yield based on grower management capabilities and irrigation application efficiency based on system used (typically 70% for overhead and 95% for drip systems).

The results of an economic assessment of the two sites based on the IRRIECON DSP are given in Table 4, which indicates the increase in nett operating income (NOII) when changing to irrigation and the percentage years the scheme would give a positive return on investment.

Table 2 : Simulated sugarcane yield for two sites in the Mhlathuze catchment

	Nkwaleni		Felixton	
Mean annual rainfall (mm)	719		1190	
PET (mm)	1171		1419	
	Good soil	Poor soil	Good soil	Poor soil
Dryland yield (tc/ha/an)	41 (10–101) **	34 (8-90)	79 (48-104)	66 (47-94)
Irrigated yield (tc/ha/an)	94 (85-105)	76 (68-87)	108 (88-121)	92(82-105)
Yield increase (tc/ha/an)	53 (0-94)	42 (8-68)	29 (0-70)	26 (3-55)

** Average (worst – best) yield

Table 3. Illustrative costs used in example IRRIECON economic assessment.

Irrigation System Capital Cost	R8000/ha (Overhead System)
Salvage value	R800,00
System life	15 years
Irrigation System Annual Fixed Costs	
Interest rate	16%
Depreciation (% capital cost)	5%
Maintenance (% capital cost)	5%
Irrigation System Annual Variable Costs	
Management and labour cost	R400/ha
Water	7,5c/kl
Power	20c/kWh
Power cost per mm irrigation	R2,47/ mm
Land Management Costs	
Harvest and transport costs	R35/tc
Ratoon management costs	R2000/ha/an
Crop establishment costs	R5000/ha
Revenue	
Sucrose (%)	12,5%
Sucrose price	R1000/t

Table 4. Results of economic assessment for overhead sprinkler system.

	Nkwaleni		Felixton	
	Good soil	Poor soil	Good soil	Poor soil
Dryland yield (tc/ha/an)	41(10-101)**	34(8-90)	79(48-104)	66(47-94)
Irrigated yield (tc/ha/an)	94(85-104)	76(68-87)	108(100-121)	100(94-111)
Yield increase (tc/ha/an)	53(5-82)	42(8-68)	29(6-70)	26(2-55)
Average annual NOII (R/ha)	1891(-2200to5200)	1432(-1400to3200)	-208(-3000to3000)	-57(-2000to2100)
% Years with +ve NOII	87%	85%	44%	47%

** Average (worst – best) yield/return

The results show a high NOII at Nkwaleni for both good and poor soils, where in 87% of years irrigation would have been profitable on good soils. Returns for Felixton would be lower owing to a wetter climatic regime and better dryland yields. Nevertheless investment in an irrigation system could provide a significant advantage in dry years.

Results above highlight why farmers in the Heatonville/Nkwaleni area have made high investments in irrigation and why dryland production is not viable in the area. Towards the coast, as represented by Felixton, as well as in the higher altitude inland areas, irrigation is less common, although local conditions, such as poor soils or low rainfall, can make it financially viable.

GIS can be useful to assess and illustrate trends in profitability across a region based on empirical trends derived from the CANESIM and IRRIECON models. Figure 2 illustrates the NOII based on the assumptions of Table 3 for the Mhlathuze catchment, illustrating the much higher return on investment in irrigation in the traditional irrigation areas of Heatonville/Nkwaleni and lower returns in coastal and higher elevation inland areas.

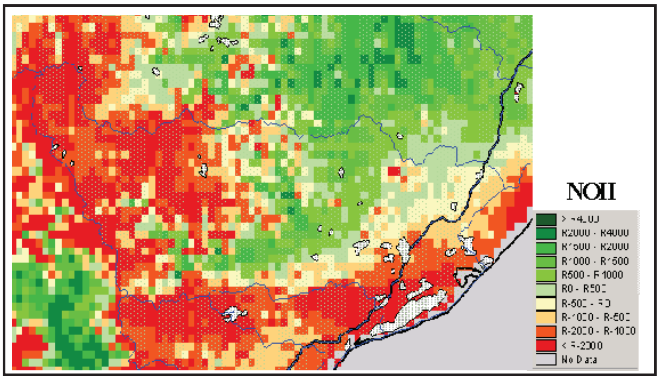

Figure 2 : Trends in the increase in nett operating income (NOII) for a good soil, when changing from dryland to irrigated production (economic assumptions given in Table 3).

Why not change to more efficient irrigation systems?

Overhead irrigation systems have low application efficiencies, typically between 60 and 80%. There is a strong argument to introduce more efficient systems, such as drip irrigation, particularly on shallow soils, where small volumes of water can be applied daily to maximise production. Water application efficiencies can be up to 95% with drip systems, although poor design and maintenance can limit this efficiency significantly. While drip irrigation requires a high capital outlay, lower operating costs result, due to water and power savings.

Selection of an irrigation system is affected by many factors. DSPs such as CANESIM and IRRIECON can help identify where a particular system will be most viable. Table 5 indicates the NOII when using drip irrigation at Nkwaleni and Felixton on both poor and good soils. Changes to the economic information of Table 3, to reflect drip irrigation costs, include increasing capital cost to R15 000 per hectare and reducing pumping cost to R1,48/mm to account for a lower pumping head. Comparing Table 5 with Table 4 it is evident that drip irrigation provides the greatest increase in yield, when compared with an overhead sprinkler system, in instances of poor soils with a low water holding capacity. The best return on investment in drip irrigation is found in the dry Nkwaleni region, especially on poor soils. These results illustrate that investment in expensive drip irrigation systems can be profitable but depend on local conditions. The results shown are very sensitive to assumptions made, particularly in terms of yield and costs and need to be developed for a specific grower, based on his situation.

Are current water allocations fair, or do they exceed crop water requirements?

Historical records of water use by the five Mhlathuze irrigation boards, shows measured utilisation, over the past five years, to be typically around 40% of the water allocation. This has

Table 5. Results of economic assessment for drip irrigation system.

	Nkwaleni		Felixton	
	Good soil	Poor soil	Good soil	Poor soil
Yield dryland (tc/ha/an)	41 (10–101)**	34 (8-90)	79 (48-104)	66 (47-94)
Yield irrigated (tc/ha/an)	98 (92-107)	98 (92-107)	115 (114-122)	115 (114-122)
Yield increase (tc/ha/an)	57 (2-89)	65 (22-89)	36 (11-71)	49 (25-72)
Average annual NOII (R/ha)	1391(-3500to4800)	1759(-2000to4200)	-705(-4000to3000)	101(-2200to3100)
% Years with +ve NOII	65%	85%	40%	52%

** Average (worst – best) yield/return

prompted a call by authorities for a reduction in irrigation allocations on the assumption that they are excessive. Table 6 gives estimates of nett and gross irrigation requirement for Nkwaleni and Felixton, based on the CANESIM model assuming an overhead irrigation system applying on 25mm nett every seven days, when the soil can accept the water. Values in brackets represent irrigation requirements during wettest and driest years of the simulation period. Gross requirement assumes an application efficiency of 70%.

Current water allocation for irrigation boards in the Mhlathuze catchment vary from 1260 mm at Nkwaleni and 1180 mm at Heatonville to 900 mm in the lower Mhlathuze catchment, and do not appear excessive when compared with the gross requirement given in Table 6. During wet years irrigation requirement is substantially reduced. In shallow soils less water can be applied owing to limited soil water holding capacity.

The low water usage figures of the past five years do not appear to be due to an over-allocation. There are many other operational factors that are likely to have affected water use, including:

- Undeveloped land and temporarily abandoned land for which an allocation is available.
- Insufficient irrigation equipment to apply full water requirements
- Installation of more efficient systems (e.g. drip) where water savings are possible.
- Weather patterns reducing irrigation requirement.
- Difficult shallow soils where it is difficult to apply the required amount and timing with current systems.

Is it possible to make water savings through better scheduling?

Scheduling refers to putting the right amount of water on the crop at the right time, accounting for soil water status. Different strategies for scheduling are possible. One farmer may wish to maximise yield another minimise water applied per hectare, in order to maximise use of natural rainfall and stretch water allocation over a larger area. Scheduling decisions are often aided by using soil moisture meters or by keeping a budget of soil water status using models and weather data.

Figure 4 illustrates, for a good soil at Nkwaleni, trends in gross irrigation applied (mm), expected yield (tc/ha) and water use efficiency, WUE, defined in this example as yield per 1000 mm of irrigation water applied. The trends were derived using the CANESIM model and are given for various irrigation scheduling scenarios as depicted by the amount of water applied (e.g. 25 mm), the duration between irrigations in weeks (e.g. 1w) and whether scheduling was employed (sched). Scheduling, in the model, ensured that water was applied only when there was sufficient capacity in the soil. Figure 4 illustrates that there are significant savings in water when scheduling, with no loss in yield and higher WUE. While a strategy of putting on small amounts of water infrequently provides maximum WUE, yields are reduced, which affects the profitability. The example given has been for a fixed cycle overhead sprinkler system. Further gains can be achieved by applying small amounts of water more frequently using drip irrigation systems. Consideration must, however, be given to the financial issues discussed previously.

Would reducing the area under dryland sugarcane be an option to conserve water?

Dryland sugarcane dominates the inland areas of Eshowe and Melmoth, as well as the coastal areas surrounding Empangeni and Felixton. The new Water Act designates those dryland crops, which use more water than 'natural vegetation', and therefore reduce natural streamflow, as streamflow reduction activities (SFRA). In terms of the Act any land use, which reduces streamflow 'significantly', must be controlled via a water use licence. Where water allocations exceed available resources, such controls could conceivably include a reduction in crop area.

SASEX research to assess the hydrological impact of irrigated and dryland sugarcane was described earlier. The ACRU model, together with the ACRUQuery database and Genscn visualisation tool, provides a powerful resource to assess trends. Results of this work has shown that the impact of sugarcane on streamflow depends on many factors, most importantly climate, natural vegetation being replaced, soils and crop management practices (Schulze *et al.*, 1999). Other important issues to consider are whether it is a wet or dry year, winter or summer, and

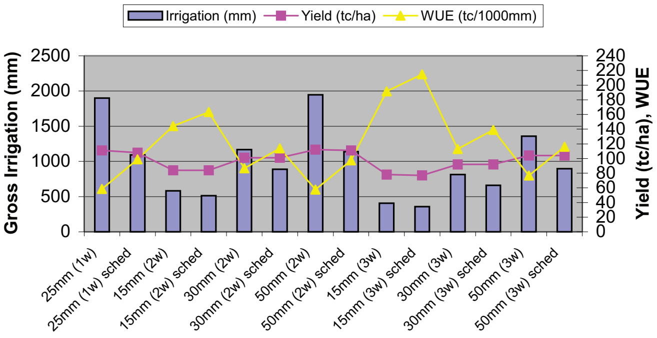

Figure 4. Gross irrigation requirement (mm), sugarcane yield (tc/ha) and water use efficiency (WUE) for good soil at Nkwaleni, based on CANESIM model.

Table 6. Estimated irrigation requirement using an overhead sprinkler system applying 25mm every 7 days.

	Nkwaleni		Felixton	
	Good soil	Poor soil	Good soil	Poor soil
Nett requirement (mm)	830 (550-1100)	555 (400-850)	766 (550-1050)	536 (400-850)
Gross requirement (mm)	1185 (700-1600)	792 (500-1100)	1094 (700-1500)	765 (440-1050)

** Average (wet – dry) year

whether base flows or storm flows are most important. Also important is the impact on system yield and the location and extent of competing water users.

An assessment of the streamflow reduction potential of dryland sugarcane, based on the ACRU model (Schulze *et al.,* 1999), for the Mhlathuze catchment, shows annual average streamflow reduction to be on average 40 mm/ha, but varying from 7 mm/ha to 83 mm/ha, depending on region and soil type. Accounting for the distribution of dryland cane within the Mhlathuze the annual average volumetric reduction in streamflow would be approximately 12 million m^3/annum. Assuming annual average dryland sugarcane production in the Mhlathuze to be approximately 1,5 million tons cane (yields of 40 tc/ha/an in higher elevation areas and 65 tc/ha/an in coastal areas from 25 550 ha) this equates to approximately 0,125 tc/m^3 of streamflow reduction. Applying a similar analysis to irrigated sugarcane, based on current water allocations (1260 Ml/ha – 900 Ml/ha), production areas (12 000 ha) and yields (90 to 100 tc/ha/an), results in a figure of 0,009 tc/m^3 of irrigation water abstraction. This value would be reduced if one accounts for actual water usage by irrigators.

The above analysis suggests that dryland sugarcane production is a very efficient user of water when compared with irrigated sugarcane. Reducing the area under dryland cane, for water conservation purposes, would not be the most viable option. It should also be noted that the reduction in usable water or system yield by dryland cane will be substantially less than the 12 million m^3 streamflow reduction mentioned above, since the greatest impact of sugarcane will be on the stormflow component of streamflow, which follows directly after a rainfall event and cannot be fully exploited without storage. Baseflow, the delayed component of streamflow, is the most usable component on an unregulated stream and in many cases is enhanced by a change from natural vegetation, such as veld, to sugarcane. Furthermore many of the dryland cane areas are located near the coast resulting in fewer competing water users.

Conclusions

The Mhlathuze catchment is typical of many areas where competition for water is forcing a re-assessment of water management practices. This paper has described a number of decision support programmes (DSPs), which can be of assistance to decision makers. Applying the DSPs to the Mhlathuze catchment helps quantify a number of key issues, many already well recognised by local farmers.

There are marked changes in climate, especially rainfall, within the Mhlathuze catchment, which influences irrigation viability. Dryland production is not viable in the Nkwaleni/Heatonville regions and there is a need to invest in irrigation systems. In higher rainfall areas such as Felixton, irrigation is less viable but can provide an economic advantage on poor soils, especially during dry years.

There is a strong argument to change from overhead sprinkler irrigation systems to more efficient methods such as drip irrigation to save water. Any decision to change systems must account for the anticipated yield increase and water saving as well as the new fixed and variable cost structure. Use of CANESIM and IRRIECON for the Mhlathuze catchment illustrates that a better return on investment in drip irrigation is found in the drier areas of Nkwaleni/Heatonville, especially on poor soils.

Use of crop models such as CANESIM indicates that current water allocations for irrigation in the Mhlathuze are not excessive. A number of operational reasons have resulted in water use being well below allocation over the past five years. By scheduling irrigation significant savings in water can be achieved, with no loss in yield and higher yield per unit of water. Maximum profitability does not, however, occur with maximum water use efficiency.

ACRUQuery and Genscn provide useful tools to interpret the impact of sugarcane on water resources, as derived by the ACRU agrohydrological model. The local climate, natural vegetation being replaced, soils and crop management practices all influence the extent to which sugarcane reduces streamflow markedly. Dryland sugarcane production has been shown to be a very efficient user of water when compared with irrigated sugarcane, and reducing area under dryland cane for water conservation purposes would not be viable.

It is important to recognise that results shown in this paper are sensitive to assumptions made and serve solely as examples. Specific assessment needs to be developed for each grower based on his situation. The value of the DSPs discussed is that they allow any number of alternatives to be explored.

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