Water in the Australian Sugar Industry

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A CRC Sugar Technical Publication April 2002
CRC for Sustainable Sugar Production, Townsville. 69pp.

ISBN - 1 876679 19 0
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Sugar production in Australia takes place along the eastern seaboard from Grafton in northern New South Wales to Mossman in far north Queensland, and in the Ord River Irrigation area of north Western Australia. The Australian industry produces roughly 4.4% of world production, and is one of the world’s largest exporters with more than 80% of the sugar produced being exported. This equates to roughly 12% of world exports (ABARE 1998). Sugar is by any measure an important component of the Australian economy.

Within the Australian sugar industry there are approximately 7000 farms generally ranging in size from 50-250 ha involved in producing sugarcane. More than 545,000 ha of land is assigned for sugarcane production. The soils, climates and social pressures vary widely across the industry and have resulted in different approaches and farm management practices in different regions. As an example, the Burdekin, parts of the Atherton Tableland and Ord River districts are dependent on irrigation, the Mackay and Bundaberg regions have supplementary irrigation, and the Wet Tropics and Northern New South Wales are driven by rainfall.

A large part of the Queensland sugar industry also lies adjacent to World Heritage listed areas, the Wet Tropics, Rainforests, the Great Barrier Reef and the Great Sandy Region. This has in recent years focussed attention on the industry in terms of the types of practices used and their impacts, or likely impacts, on the surrounding environments. Governments and Environmental groups have in particular increased their level of scrutiny of the industry, challenging the need for further expansion, and demanding implementation of better natural resource policy and planning processes to minimise impacts of current and future practices.

Like other sectors of the Australian economy, the sugar industry is critically dependent on reliable supplies of good quality water. Although the industry needs this water for both the on-farm production and off-farm milling sectors, this report focuses on the on-farm needs and the on- and off-site impacts associated with the way water is used and managed on-farm. Despite the present strong focus on catchment scale issues, water and nutrient management usually takes place at the paddock (or block) scale. It is at this management unit scale, that the opportunity exists to make large differences in how water and nutrients are managed. The consequent impacts of management decisions made at the paddock scale may be expressed at the paddock, or farm, or catchment scale, and it is these impacts that will reflect very strongly the progress or lack of progress made in improving on-farm management practices. Although much of the CRC Sugar research on water has been carried out at the paddock or field scale, it has been couched within a larger framework to allow seamless incorporation into a broader catchment setting (Figure 1-1.)

Rainfall, the ultimate source of water, is highly variable in both space and time across the industry, with amounts ranging from roughly 1000 mm yr-1 in some districts (eg. Bundaberg) to more than 4000 mm yr-1 in others (eg. Tully). This highlights the need for a range of management strategies across districts, with drainage of excess water being most important in some districts, and implementation of effective irrigation management strategies being critical in other districts. Roughly 100 mm of water (equivalent to 1 megaliter per hectare) is needed to produce 5—15 t/ha sugarcane, so ongoing efforts are needed to ensure improvements in water use efficiency.

While water is essential for plant production, it also affects the way solutes (nutrients, chemicals and salts) are stored and transported.
across and through soils. Management of solutes, no matter the source, is therefore inextricably linked with water management, and care is needed to ensure implementation of appropriate strategies to minimise negative environmental impacts associated with inappropriate water and/or solute management practices. In some situations particular emphasis needs to be given to water management, since if water is appropriately managed within the root zone, the solutes will be as well. In other situations however, such as in the high rainfall wet tropics, it is not possible to control the timing and amount of water. In these cases emphasis needs to be given to ensuring implementation of appropriate solute management strategies so as to avoid unwanted impacts of solutes moving beyond their zone of need.

Because of its importance to the sugar industry and the natural environment there are obviously a number of groups from various Australian organisations working on water related issues within the industry. CRC Sugar has contributed significantly to water research and development in the sugar industry. It has focused its efforts on facilitation of multidisciplinary teams and on priority development and application of integrative frameworks to address multi-faceted and complex issues. A feature of its work has been the development of strong links between industry client groups and scientists from key collaborating organisations. In doing this, CRC Sugar has fostered participatory relationships to tackle issues that are often socially, environmentally and scientifically complex, and traditionally difficult to deal with.

Key water related areas where CRC Sugar has invested its efforts and which are discussed in more detail in this monograph include:

- Development of improved irrigation practices to optimise use of limited water supplies
- Improved irrigation through investments in and improved management of on-farm water storages
- Use of effluents as a resource for irrigation
- Land-use impacts on water quality
- Nitrogen and groundwater quality
- Improved understanding of pesticide management and water quality
- Analysis of community concerns about water related issues

CRC Sugar’s approach has been to foster a more integrated effort that links experimental and modelling approaches to address key water-related issues. Field and/or laboratory experiments have been used to address knowledge gaps on specific issues. The site and season specific nature of experimental work was acknowledged from the outset and CRC Sugar has pioneered the integration of experimental work within appropriate modelling frameworks in the sugar industry. Modelling tools have been developed and/or enhanced to represent the biophysical and economic systems and used to deal with complex interactions, competing demands, spatial and temporal variability, scenario analysis and extrapolation of findings in both space and time.

To achieve its objectives on water use efficiency, CRC Sugar established a close and effective collaboration with the Agricultural Production Systems Research Unit (APSRU), made up of CSIRO Sustainable Ecosystems, DPI and DNR staff in Toowoomba and Brisbane. This relationship has enabled ongoing application, testing and improvement of the APSIM-Sugarcane model, and development and application of a range of other software tools and packages required and used by CRC Sugar and collaborating partners. When integrating biophysical and economic analyses, CRC Sugar has also attempted to understand at least some of the social aspects involved to provide a more holistic approach to each issue. This has been achieved in part by the conduct of research with the active participation of various client groups who have provided the impetus for much of the work carried out within CRC Sugar. The aim in encouraging use of this participatory approach has been to implement more meaningful change with long-term benefits. The cane growing sector of the industry has also sought answers to questions on water quality condition, trend and impact, outreaching to off shore waters.

References
2. Best Irrigation Practices with Limited Water

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Introduction

Approximately 545,000 hectares are under cultivation to sugarcane in Australia, 93% of which is in Queensland. About 40% of this area is irrigated either to supplement rainfall or because irrigation is essential for crop growth as in the Burdekin, parts of the Atherton Tableland and Ord (WA) regions. For other regions, irrigation may not be essential to produce a harvestable cane crop but it improves yields and reduces risks of cane farming which is otherwise subject to unreliable rainfall. However, high rainfall variability leads to complex problems in the installation and operation of supplementary irrigation systems.

An early question is whether or not a grower should invest in an irrigation system in the first place because water supply is limited in most regions and crop water requirements cannot be fully met in many years. In some years no irrigation is required at all. Then there are questions about on-farm water storage, water demand by the crop at various growth stages, irrigation of plant crops at the expense of ratoon crops, irrigation of a wide variety of soils, which variety to use, risks of waterlogging and how to schedule irrigation. On top of uncertainty about these biophysical issues, there are uncertainties about the sugar price, the cost of water and other irrigation costs. Despite many unanswered questions, supplementary irrigation has increased throughout the industry and is one of the main reasons and hopes for improved yields and economics of cane farming. In addition, sewage effluent from urban centres is becoming available and should be considered as a limited but reliable source water for cane farms close to those centres. Economics of supplementary irrigation in these areas needs to be integrated with costs and benefits of processing sewage effluent for use in cane irrigation.

CRC Sugar recognized both the importance and problems of supplementary irrigation and developed an appropriate activity, which is the subject of this section, in regard to the impact of the activity on water related issues in and outside CRC Sugar.

Contributions to this activity were made by 21 people from 6 organisations. While formal work plans were developed by each member of the team, progress was made more as a result of interactions between team members in less formal ways. The rich but heterogeneous background of different team members led to a fresh review of a number of biophysical attributes of the problem. Many longstanding views were challenged, some held up to new scrutiny. Others were modified. The aim of this section is to summarize progress on a number of biophysical and economic issues important to use of limited water. It describes how technology has developed and been extended at least to those who are now advising growers on best use of limited irrigation water.

Growers situation and perceptions

The situation in which growers find themselves regarding the supply and demand for water is illustrated in Table 2-1. A common feature in each region is that allocation of water is inadequate to meet average irrigation requirement. In reality, average conditions do often occur and the allocation will be grossly
Focus meetings were held in a number of these regions during 1998 and 1999 to assess problems faced with limited irrigation and to determine the scope for addressing these problems within this activity. Perceptions about problems and possibilities varied between growers and regions. Concerns for this activity are summarized by region below:

**Bundaberg**

Bundaberg growers believe their allocation is inadequate to meet crop demand and only a limited amount of the allocation is sometimes available. ‘Out-of-allocation water’ leads to inefficiency of water use because it is often used when not needed. Scheduling is determined by water availability rather than crop stress or scheduling devices. Importance is placed on getting plant and ratoon crops away to a good start. This view was common to most regions.

**Kelsey Creek**

Kelsey Creek growers in the Proserpine area are new to irrigation, as the scheme has only operated over the last two years. December to March is regarded as the critical irrigation period. Growers concentrate irrigation on plant and ratoon cane, while older ratoons are rainfed. Growers believed the 4 ML/ha allocation could raise productivity by 25 t/ha. Irrigation scheduling and cycle times (average is 3-weeks) are limited by infrastructure. Scheduling is based on visual crop symptoms at present but there is some interest in use of tensiometers. Growers are aware of soil differences but acknowledge a lack of understanding about soils.

**Waterson / Upriver**

The Waterson / Upriver region has 3-5 ML/ha allocated from the Proserpine River at a cost of $12/ML, excluding pumping costs. The critical irrigation period is between December and February. Growers do not have the infrastructure necessary to irrigate on demand and minimum cycle period is about three weeks. Growers are uncertain when to irrigate after rain and what soil deficit to allow before starting irrigation again. Irrigation is applied differently to different soil types. Some growers irrigate before harvest to encourage ratoon growth. Plant and ratoon crops are not irrigated differently necessarily. Risk of waterlogging young crops after irrigation is a concern.

**Atherton**

In the Atherton region, growers realized the advantage of applying smaller amounts of irrigation to young crops and larger amounts to older crops. There is confusion over economics and efficiencies of different irrigation systems. Growers support the use of models by researchers to solve their problems.

**Mackay**

In the Mackay region, the first irrigation after harvest is most important and then irrigation around the Christmas period. Growers are
aware of scheduling tools but there is uncertainty on how to use them. Past experience with minipans was unconvincing. Cycle times are between 10 and 14 days and an application of 50 mm per irrigation is considered desirable without much regard to soil type. There is interest in using the internet to assist with rainfall prediction and irrigation scheduling. Irrigation practices would not change with sugar price as the main aim with irrigation is to protect the stool. Growers regard a 30-day dry off period prior to harvest as appropriate.

**Soil water storage**

When allocations are lower than demand for water, crops are forced to use the full storage capacity of the soil. Strategies for the use of limited water are therefore more dependent on knowledge of plant available water capacity (PAWC) than is the case for full irrigation systems. While a number of Australian sugar soils have been evaluated for storing readily available water (RAW) (Shannon et al. 1996, Zund and McDougall, 1997) few have been assessed for PAWC. PAWC is defined as amount of water plants can extract after significant drainage (>1 mm per day) has ceased even if they die in the process. RAW is defined as the amount extracted when stalk growth is reduced 50% by water stress. Soil water storage and supply were debated vigorously in CRC Sugar for a number of reasons. There was disagreement about the usefulness of deep ‘ineffective’ roots and water remaining after RAW had been extracted. Then there was a requirement that all CRC Sugar experimental sites be characterized according to the ‘minimum dataset’ guidelines of Mazzucchelli and Prestwidge (1999), and most collaborators were experiencing difficulty in putting these guidelines into practice.

There is consensus within CRC Sugar that PAWC needs to be known to develop optimum irrigation strategies. While appropriate soil characterization is still a limitation in the development of these strategies, two options were provided to allow use of real or realistic PAWC in determining best-bet strategies with current knowledge. Hydraulic properties typical for a sand, loam, clay and heavy clay were developed. These four ‘typical’ soils have been used extensively to develop irrigation strategies and to benchmark effective rainfall, water use efficiency and productivity. Another option was developed recently, based on inverse modelling to estimate PAWC and maximum rooting depth from RAW measurements and standard soil survey information. PAWC was estimated for a number of Bundaberg soils in this way (Table 2-2).

<table>
<thead>
<tr>
<th>Soil order*</th>
<th>Soil profile class</th>
<th>RAW (mm)</th>
<th>PAWC (mm)</th>
<th>Max. rooting depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aeric Podosol</td>
<td>Colvin</td>
<td>40</td>
<td>83</td>
<td>1.90</td>
</tr>
<tr>
<td>Yellow Chromosol</td>
<td>Isis</td>
<td>46</td>
<td>88</td>
<td>1.90</td>
</tr>
<tr>
<td>Yellow Dermosol</td>
<td>Kepnock</td>
<td>48</td>
<td>113</td>
<td>1.15</td>
</tr>
<tr>
<td>Black Vertosol</td>
<td>Maroondan</td>
<td>54</td>
<td>110</td>
<td>0.70</td>
</tr>
<tr>
<td>Red Kandosol</td>
<td>Oakwood</td>
<td>79</td>
<td>150</td>
<td>1.60</td>
</tr>
<tr>
<td>Yellow Dermosol</td>
<td>Kepnock</td>
<td>82</td>
<td>132</td>
<td>1.60</td>
</tr>
<tr>
<td>Red Kandosol</td>
<td>Oakwood</td>
<td>84</td>
<td>150</td>
<td>1.60</td>
</tr>
<tr>
<td>Red Kandosol</td>
<td>Childers</td>
<td>85</td>
<td>176</td>
<td>1.30</td>
</tr>
<tr>
<td>Red Ferrosol</td>
<td>Childers</td>
<td>87</td>
<td>142</td>
<td>1.00</td>
</tr>
<tr>
<td>Red Ferrosol</td>
<td>Watalgan</td>
<td>86</td>
<td>153</td>
<td>1.60</td>
</tr>
<tr>
<td>Red Ferrosol</td>
<td>Woongarra</td>
<td>116</td>
<td>184</td>
<td>1.30</td>
</tr>
</tbody>
</table>

*(Isbell, R.F., 1996)*
Water use efficiency (WUE)

In recent years there has been an increase in public awareness of water as a production factor and more importantly as a national resource and a major component of a fragile environment. The National Agenda for Water Reform has moved in the direction of full recovery of water supply cost, separate water and property rights, specific water allocation to the environment, and increased water use efficiency in agriculture. A new initiative on water use efficiency has been launched by DNR who have asked the sugar industry to make 60 000 ML available for irrigation from existing water resources. Definition and benchmarking of WUE has been considered by CRC Sugar.

Firstly a clear distinction was required between crop response to irrigation (CRI) and yield of cane in relation to water used over the season (Crop Water Index, CWI). The terms CRI and CWI may not be widely accepted as yet but the distinction they make is more important than the terms per se.

Crop water index (CWI)

The Bundaberg industry has been benchmarking WUE in the form of CWI for many years. CWI is defined as cane yield divided by effective rainfall plus irrigation. In the early 1990’s, a fixed 70% of the total July to June seasonal rainfall was selected as a measure of effective rainfall. This gave an average CWI in the range 7-8 t/ML cane. In the first two years, this measure proved to be a very useful extension tool focusing growers’ attention on WUE by comparing their farm results with their respective mill area average. Robertson and Muchow (1997) showed that the effective proportion of the total seasonal rainfall could vary from 56 to 81% rather than a constant 70%. Different methods were used to determine effective rainfall. In 1998 CWI reached almost 12 t/ML for the entire district. As this value was equal to the maximum level proposed by Kingston (1994), critical evaluation of the method used to calculate effective rainfall and CWI was considered necessary. This criticism and the current political climate relating to rural WUE also generated a need to re-examine the CWI benchmark. Standard settings of the APSIM-Sugarcane model have now been established in order to allow comparisons between years without confounding effects due to soil type, irrigation allocation, and cropping sequences. One reason for the high CWI in 1998 was the lack of realistic PAWC data for use in model runs. Of the four typical soil profiles available (sand, loam, clay and heavy clay), the loam option was regarded as most representative of the Bundaberg industry. Using this soil and standard model settings, trends in CWI over the period 1989 — 1998 were determined (Figure 2-1).

CWI values calculated in this way were considerably lower than the maximum of 12 t/ML reported previously but the trends are similar with the CWI increasing from about 7.2 t/ML in 1989 - 92 to 8.8 t/ML over the period 1996 - 98.

Crop response to irrigation (CRI) or irrigation water use efficiency (IWUE)

CRI is defined as the cane yield response to irrigation divided by the amount of net irrigation. In full irrigation schemes CRI and CWI will be similar because a large proportion of the water used by the crop is derived from irrigation not rainfall. With supplementary irrigation, the reverse is true. Irrigation as low as 1/10 of rainfall is applied at irregular intervals, sometimes before and sometimes
after canopy closure. Applications after canopy closure result in low evaporation losses from the soil. Applications before canopy closure may hasten canopy development resulting better in use of subsequent rainfall. Robertson et al (1997) used a simple theoretical framework out of the APSIM Sugarcane model to show that responses to limited irrigation could be as high as 22 t/ML at Mackay. Since APSIM was being used to develop best-bet irrigation strategies for limited water, it was important to see if the theory matched observed experimental results.

An experiment was conducted in 1996/97 on a Molonga series soil on a farm at Bambaroo in the Herbert. In one treatment irrigation was applied only before the wet season. Growth of experimental crops was simulated with APSIM, which helped to fill in some of the detail which could not be measured (Table 2-3).

While irrigation only was 9% of rainfall, it increased evapotranspiration by nearly 20% because irrigation was only applied when necessary and much of the rain could not be used by the crop. Irrigation resulted in an increase of 36% in transpiration because of a more rapid canopy development in the irrigated than the rainfed crops. Increased transpiration translated into a 28% or 30% increase in simulated or measured total dry biomass. The theoretical response in biomass was similar to the measured response even though the absolute biomass yields were not correctly simulated. Cane yield response was greater than biomass response because of an increase in the fraction of cane in total biomass due to irrigation (0.777 to 0.813) as well as decrease in dry matter content of cane (32.3 to 31.4). With a combination of conventional field experimentation and theoretical modelling, the activity demonstrated that large responses to limited irrigation in excess of 20 t/ML, are indeed possible.

High CRI was also demonstrated in an allocation x irrigation system x cultivar irrigation scheduling trial in Bundaberg (Ridge and Hillyard, 2000). Furrow irrigation was more efficient than usual because of short furrow lengths. The results (Table 2-4) confirmed the benchmark CWI of 12 t cane/ML proposed by Kingston (1994) and they showed that CRI can be much greater than CWI when allocations are low. However as allocation increased and irrigation became a major source of water used by the crop, CRI tended towards CWI.

<table>
<thead>
<tr>
<th>Irrigation Treatment</th>
<th>Irrigation (mm)</th>
<th>Irrigation plus rain (mm)</th>
<th>Evapotranspiration (mm)</th>
<th>Transpiration (mm)</th>
<th>Total dry biomass (t/ha)</th>
<th>Cane yield (t/ha)</th>
<th>IWUE (t/ML)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meas</td>
<td>Meas</td>
<td>Sim</td>
<td>Sim</td>
<td>Sim</td>
<td>Meas</td>
<td>Meas</td>
<td>Meas</td>
</tr>
<tr>
<td>Rainfed*</td>
<td>30</td>
<td>1658</td>
<td>1075</td>
<td>673</td>
<td>36.4</td>
<td>42.7</td>
<td>102</td>
</tr>
<tr>
<td>Irrigation</td>
<td>179</td>
<td>1807</td>
<td>1288</td>
<td>912</td>
<td>46.5</td>
<td>55.3</td>
<td>143</td>
</tr>
<tr>
<td>Response</td>
<td>9.0%</td>
<td>19.8%</td>
<td>35.6%</td>
<td>27.7%</td>
<td>29.6%</td>
<td>40.1%</td>
<td></td>
</tr>
</tbody>
</table>

* Includes initial 30mm winch irrigation to ensure establishment

<table>
<thead>
<tr>
<th>WUE index</th>
<th>Allocation (ML/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>CWI</td>
<td>9.4</td>
</tr>
<tr>
<td>CRI</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 2-3: Measured and simulated results of an irrigation experiment at Bambaroo

Table 2-4: Mean water use efficiency (t cane/ML) for different allocations averaged over drip and furrow systems and over cultivars in a Bundaberg experiment (Ridge and Hillyard 2000)
APSIM-model validation

The successful validation of APSIM-Sugarcane for crops in a variety of moisture regimes (Keating et al., 1999) has given model developers confidence that the major components of crop-water relations have been captured well enough for many model applications concerning water. However the sugar industry was understandably sceptical. Training was provided to sugar cane extension staff from a number of regions but Proserpine was given the main responsibility for model testing and use.

Several on-farm trials were established to compare irrigation strategies and to test the model’s ability to predict the results as in the Bambaroo trial (Table 2-3). Exceptionally high rainfall during 1998 and 1999 prevented many of the planned irrigation treatments. However, extension staff at Proserpine persisted in testing the model against whatever results they could glean from these trials. Model simulations could not explain some results but this was attributed to difficulties with soil characterisation and to the prevalence of watertables, which APSIM does not adequately account for as yet.

Confidence in model usage and accuracy was gained steadily. For example, at a Proserpine site, equipped with an EnviroSCAN soil moisture monitoring system changes in stalk growth and soil water content (SWC) were well correlated (Figure 2-2a). Changes in simulated and measured SWC were also similar, providing assurance that APSIM was doing the water balance correctly (Figure 2-2b). The difference in absolute SWC should not be of concern because simulated absolute SWC depends to a large extent on soil characterisation which was not available at this site.

After testing of APSIM against experimental observation and general observation of crop yield/soil water relations in Proserpine, extension staff were more convinced of APSIM as a tool for developing irrigation strategies with limited water.

Simulation of irrigation strategies for different regions

Crop simulations were conducted over a 32-year period between 1960 and 1992. In each district, simulations were configured to best represent the local environment and cropping practices. Information on each area was obtained from interviews with local irrigation extension staff and focus group meetings.

Simulated yields under both rainfed and unlimited irrigation conditions were obtained. Irrigation strategies considered after local consultation were classified as follows. 1) ‘Runout’ strategies allowed different allocations to runout after irrigating each time SWC fell to 65% of PAWC. 2) ‘Limited Strategy I’ included a single small irrigation within 10 days of planting or harvesting followed by multiple irrigations in different combinations of irrigation quantity and soil moisture deficit. 3) ‘Limited Strategy II’ included strategy I options, this time

![Figure 2-2: a) Time course of stalk elongation rate and soil moisture b) Simulated and measured soil water content using EnviroSCAN.](image)
applied differently during two variable growth periods. Table 2-5 briefly summarizes selected results of these simulations. Maximum mean yields were obtained with different strategies excluding unlimited water in different regions, which shows that no single strategy could be applied to all regions. The results also show that irrigation with current allocations will provide substantial yield gains in all regions even though these allocations are inadequate for removing water limitations to yield. Extension officers are being equipped to assess irrigation strategies using the APSIM-Sugarcane model and this should lead to improved use of limited allocations of water.

**Economics of supplementary irrigation**

The economics of supplementary irrigation are complicated by interactions of soil, climate and irrigation, by uncertainties in water supply and cost, by a bewildering combination of engineering and operational options and by uncertainty in the sugar price. The best option for dealing with the biophysical components is to be guided by outputs from the APSIM-Sugarcane model. Many, but not all, of the biophysical processes important to determine benefits of irrigation are incorporated into this model and substantial effort has been expended in testing model predictions against observed responses to irrigation and variable rainfall. Some deficiencies in the model have become clear during the testing procedure and these will be the subject of future research. Economic decisions must be made on the best information available at the time despite any deficiencies that may exist.

CRC Sugar economists developed an economic model to translate APSIM biophysical output into discounted cash flow (DCF). The economic model deals with the major financial factors growers need to consider, including provisions of the Australian Income Tax Assessment Act and Drought Investment Allowance. The model uses a database of costs of components of all the major irrigation systems available to growers to establish installation costs of a new system or upgrade costs of an old system (Schuurs & Wegener 1999).

A brief example of a DCF based on yield and irrigation simulations over a 20-year period between 1961 and 1980 in Mackay is shown in Table 2-6. A farm business on 50 ha with two partners paying the marginal tax rate was considered. Capital costs derived from costs of various components plus installation costs were $1648, $2365 and $3335 for water winch, centre pivot and trickle systems respectively. Application efficiencies assumed for these systems were 75, 85 and 90 % respectively and net irrigation per application was 37.5, 42.5 and 15.0 mm respectively. Allocations of 1 or 3 ML/ha were compared for a sand, loam and clay with 63, 114 and 162 mm PAWC. Irrigation in the simulations was applied when available water content fell to 50% of PAWC for all soils. A simple cropping system of a 12-month crop harvested green and ratooning in June each year was simulated. It was assumed that water cost $40/ML, the sugar price was $320/t and mean CCS was 13.5%.

DCF analysis showed that positive returns on investment in supplementary irrigation are by no means a foregone conclusion despite the predictions of yield responses to irrigation (Table 2-4 and Table 2-5) and the relatively high sugar price (Table 2-6). An allocation of 1 ML/ha was not economic with any system or soil texture class and no options were economic.
for the clay soil (Table 2-6). The most profitable option was a trickle system on a sandy soil with a 3 ML/ha allocation. This showed an internal rate of return of 11% and an increase in NPV over rainfed of $120 000. Centre pivot and trickle systems would both be viable on sands and loams provided water allocation was 3 rather than 1 ML/ha.

It should be emphasized that the comparison of the three irrigation systems is subject to a large number of operational rules and assumptions of the simulation. For example changes in application efficiencies and operation costs would affect economics substantially.

Generalizations about investments in supplementary irrigation are not very useful and each case has to be treated on its merits. Strategies assessed in terms of yield as in Table 2.6 should be processed through the DCF analysis that deals with year to year variation in response to irrigation.

### Development, Extension and Facilitation of Modelling Tools

Six new Rural Water Use Efficiency officers (RWUE) were employed by the new DNR initiative. Two of these people have been involved in CRC Sugar activities on irrigation. Much of the momentum for extension of activities in CRC Sugar was and is being facilitated through the RWUE Initiative.

Important steps in the transfer technology were:

1) Workshop (March 1999) on optimising use of limited water in which key findings of research were discussed. Procedures for TT were identified including the development of linkages between APSIM crop simulation, use of on-farm storages and economics.

2) Development of a user friendly interface for the APSIM-Sugarcane model called APSfront

3) The first APSfront workshop (March 1999) was attended by over 15 extension and research officers, technical assistants, and cane inspectors, from a range of industry organizations including BSES, CPPB, Mackay Sugar and Bundaberg Sugar.

4) Further APSfront Development. After the March workshop over 30 changes to APSfront were proposed and many of these were acted upon by APSRU staff in 1999.

5) Second APSfront (December 1999). Progress since the March workshop had been

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### Table 2-6: Discounted cash flow analysis of selected irrigation options at Mackay

<table>
<thead>
<tr>
<th>Irrigation system</th>
<th>None</th>
<th>Winch</th>
<th>Pivot</th>
<th>Trickle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available water (ML/ha)</td>
<td>-</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Effective irrigation (ML/ha)</td>
<td>-</td>
<td>0.75</td>
<td>2.25</td>
<td>0.85</td>
</tr>
<tr>
<td>Operating costs ($/ML)</td>
<td>-</td>
<td>96</td>
<td>96</td>
<td>28</td>
</tr>
<tr>
<td>Soil texture</td>
<td>Sand - plant available water content of 63mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average yield (t/ha)</td>
<td>87</td>
<td>99</td>
<td>120</td>
<td>100</td>
</tr>
<tr>
<td>Net present value ($)</td>
<td>-</td>
<td>-24,833</td>
<td>-40,723</td>
<td>-33,060</td>
</tr>
<tr>
<td>Internal rate of return (%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Soil texture</td>
<td>Loam - plant available water content of 114mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average yield (t/ha)</td>
<td>111</td>
<td>122</td>
<td>141</td>
<td>124</td>
</tr>
<tr>
<td>Net present value ($)</td>
<td>-</td>
<td>-53,463</td>
<td>-76,585</td>
<td>-58,503</td>
</tr>
<tr>
<td>Internal rate of return (%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Soil texture</td>
<td>Clay - plant available water content of 162mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average yield (t/ha)</td>
<td>127</td>
<td>136</td>
<td>153</td>
<td>137</td>
</tr>
<tr>
<td>Net present value ($)</td>
<td>-</td>
<td>-97,437</td>
<td>-115,030</td>
<td>-86,029</td>
</tr>
<tr>
<td>Internal rate of return (%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
substantial. Many attended for the second time. All participants including five RWUE
officers indicated their intention to use the model in their future work.

6) Workshop on Techniques in Irrigation
Research, Extension and Modelling (October
1999) conducted over four days. The
workshop brought together over 35 people
from a variety of organizations including,
BSES, CSIRO, CRC Sugar, IAMA, DNR,
USQ, DPI, Productivity Boards and
equipment manufacturers and suppliers.

The workshop included theory and practical
sessions on measuring input parameters for
running both APSIM and SIRMOD models.
These included soil moisture, drained upper
and lower limits, irrigation inflow, runoff
and infiltration. SIRMOD simulates flow of
water down a furrow and allows uses to
design optimum flow rates, furrow shapes
and slopes.

Dam Ea$y

It was clear after consultation with researchers,
extension officers and cooperating growers that
progress on a number fronts (biophysical,
economic and technology transfer) needed to
be collated into a tool that could be used by
advisors and financiers to assess the benefits
and risks of on farm storage supplementary
irrigation for the particular financial and
biophysical circumstances of individual
growers. Development of a product called Dam
Ea$y has drawn on the combined wisdom and
skills of a number of people within CRC Sugar,
including those working on methods for
determining optimum combinations of on-farm
storages, catchment size and use of out of
allocation water based on variable river flows.
Dam Ea$y is described in the next section.

Irrigation Scheduling and Scheduling
Tools

While most attention has been directed at long
term strategies and efficiencies of limited water
use, some effort was directed at tactical issues
such as irrigation scheduling and optimum use
of allocation on-farm in a particular season.

Irrigation scheduling in the Burdekin

Current recommendations for irrigation
scheduling are based on Class A pan
evaporation and evaporation from locally
calibrated ‘minipans’ (Holden, 1998). The
minipan technique has been particularly
successful because of concerted efforts to
involve growers in the development of the
technique and its application (Shannon, et al,
1996b). A replicated trial was established in
May 1998 to compare minipan pan scheduling
as now practiced, best practice Class A pan
scheduling, a novel ‘EnviroSCAN’ method and
a more sophisticated minipan technique.

EnviroSCAN is a capacitance device that is
calibrated to measure soil water content at
various soil depths. First year results revealed
no yield differences between scheduling
methods suggesting there is no advantage in
using more sophisticated (and more expensive
in the case of EnviroSCAN) methods. However,
more testing is required to determine benefits
of more elaborate scheduling devices.

Optimum use of allocation on-farm in a given
season

Once a grower has selected a best-bet
supplementary irrigation system and strategy,
the question remains as how to best use water
allocation to the farm in a given year. This
allocation may be lower than that of the
scheme design. Alternatively, opportunities
may exist to buy additional allocation or to use
out of allocation water. CRC Sugar developed
a procedure based on linear programming to
maximise returns from limited allocation of
water between plant and ratoon crops, and
between soil texture classes, using a range of
scheduling options (Brennan et al 1999). This
procedure showed that returns from limited
water supply could be increased by allocating
and scheduling irrigation depending on crop
class and soil type.

While further research is required to confirm
simulations of marginal responses to water, it
has been demonstrated that, once optimum
long-term strategies have been found for a
grower, there is further scope to optimise water
use for each season. The work also highlighted
a number of biophysical knowledge gaps that have high leverage in devising optimum economic solutions and require further investigation.

References


3. Improving Irrigation Management Through On-Farm Water Storages

Shaun Lisson\textsuperscript{1,2}, Lisa Brennan\textsuperscript{3,2}, Keith Bristow\textsuperscript{4,2}, Brian Keating\textsuperscript{3,2}, Dene Hughes\textsuperscript{3,2}, Tony Linedale\textsuperscript{5,2} and Mike Smith\textsuperscript{6,2}

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\textsuperscript{2} CRC for Sustainable Sugar Production, JCU, Townsville, QLD 4811
\textsuperscript{3} CSIRO Sustainable Ecosystems / APSRU, 120 Meiers Road, Indooroopilly, QLD 4068
\textsuperscript{4} CSIRO Land and Water, PMB Aitkenvale, Townsville, QLD 4814
\textsuperscript{5} BSES, PO Box 953, Bundaberg QLD 4670
\textsuperscript{6} Bundaberg Sugar Ltd., PO Box 500, Bundaberg, QLD, 4670

Introduction

Water storages are in many instances critical to ensuring reliable supplies to meet irrigation demand as and when it occurs. While large-scale storages are managed as part of an irrigation scheme, there is at present no formal coordination/management of smaller on-farm water storages (OFWSs). Furthermore there is no overall assessment of their effectiveness and impact that can serve as a benchmark against which to measure future changes. As demand for water from all sectors of the economy increases, there are likely to be increasing numbers of OFWSs as farmers look to maximise their security of water supply, increase their irrigation management flexibility by accessing out of allocation and potentially tradeable water, and optimise their management of available water resources. There is also the potential for OFWSs to play an important role in managing tailwater and water quality both on the farm and as it leaves the farm. This means that both environmental and economic issues associated with OFWSs need to be taken into account when considering investment in, and subsequent management of OFWSs.

The decision to invest in such storages requires assessment of a range of biophysical, economic and social factors, and the interactions between these factors. Within the biophysical arena, there are complex interactions between OFWS design characteristics, farm management, crop, climate, soil type and catchment related factors. Economic feasibility is sensitive to many variables including cost of installation, method of repayment, and year to year fluctuations in yield and sugar price. Computer simulation models can capture many of these processes and their interactions and provide a useful decision support capability for farm advisors (extension officers and/or agribusiness consultants). With this in mind, a software package is being developed within CRC Sugar, called Dam EaSy (Bristow et al. 2000), 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.

The development of such a package is ideally suited to CRC Sugar in that it requires a broad skill base in crop and soil science, economics, modelling and software engineering, a set of modelling tools, and an environment in which such resources can be harnessed and integrated in a collaborative and constructive manner. This package builds on a substantial body of work that has, and continues to be, conducted within CRC Sugar relating to the development, training and application of biophysical and economic modelling tools within the sugarcane industry, as described in the previous and following sections.

This section describes the various components of the Dam EaSy package and demonstrates its capability via a case study in the Bundaberg region. 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 by its developers to other growing regions.
Dam Ea$y

Dam Ea$y consists of three main components: 1) a database of pre-run biophysical model output for a range of OFWS-based production systems, 2) a ‘real-time’ economic model, and 3) an interface through which the operator interacts with the package (Figure 3-1). Production systems of interest to the operator are ‘constructed’ within Dam Ea$y by selecting from a discrete number of ‘optional’ variable settings (eg. irrigation area, OFWS capacity) contained in drop-down menus within the user interface. This construction process serves to identify system designs held within the biophysical database that match or come close to matching the farmer’s specific needs. Other biophysical variables are ‘fixed’ to values representative for the region in question. The operator also sets a number of economic variables (eg. sugar price, interest rates) 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.

Biophysical database

Although the current prototype version of Dam Ea$y has a fairly small database, when fully completed, the biophysical database will cover in excess of 50,000 system designs. These will represent current practices in the region of interest, as well as alternative designs for the purpose of scenario or ‘what if’ analyses. The biophysical databases are created using the systems model, APSIM (Agricultural Production Systems sIMulator) (McCowan et al. 1996). Model runs are conducted for each system design over a 40-year period, to capture responses to season-to-season climate variability, and to enable short to medium-term investment analysis. APSIM can be configured to enable simulation of the production system of interest, irrigated using water from any combination of OFWS, out of allocation (OOA), or scheme allocation (Figure 3-2).

Allocation water

The allocation is defined by an amount (ML/ha) and a period over which it is accessible to the farmer. In many irrigation schemes, the carry-over of unused allocation water from one allocation period to the next is not allowed. Hence, in order to minimise the volume of ‘carry-over’ water, farmers often transfer surplus allocation water into the OFWS for use at some future time. This is captured in Dam Ea$y through the transfer of allocated water into the OFWS (if present), during a pre-defined period at the end of the allocation period.

Out of allocation water

OOA water is available for irrigation when the daily flow rate within the irrigation scheme exceeds certain limits. When OOA water is available and not being used for irrigation purposes, it is used to top up the OFWS (if present).

On-farm water storage

The operator can select from a number of

Figure 3-1: Structure of Dam Ea$y

Figure 3-2: Framework of biophysical model
OFWS capacities and catchment areas from which runoff is received. In the model, 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 \( (R_u) \), 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:

\[
V_{ofs} = (R_u + R_{ofs} + T + A_t + O_t) - (E_{ofs} + I + S + O_v) \quad (1)
\]

In the absence of measured, site-specific data, daily catchment runoff is estimated using the QDPI model called 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 calculated from the depth, volume, and surface area relationships for the storage. Seepage losses are estimated using algorithms (Horton and Jobling 1992) and depend on the head of water in the storage and the permeability 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.

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 and to increase the capture of runoff. The drying-off period and the irrigation cycle length are set to current management practices. The operator selects the deficit to irrigate \( (\text{mm}) \), the efficiency of irrigation application \( (\%) \), and the irrigation area \( (\text{ha}) \).

**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 a spreadsheet model (Schuurs 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 system designs. Additional physical and financial parameters characterising the farm must also be specified by the operator of Dam Ea$y. These data include farm size, cane area lost to the OFWS structure, scheme allocation, scheme allocation water price, OOA 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.

The analysis considers the irrigation investment in the context of a farm business subject to income tax, and eligible to claim deductions for 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 this Act have been incorporated into the economic model.

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.
Bundaberg Case Study

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. A case study was conducted to investigate the costs and benefits of investing in an OFWS for a sugarcane farmer in Bundaberg, currently operating with access to a small scheme allocation (3 ML/ha) and OOA water only (hereafter referred to as the ‘benchmark’ design). The key biophysical characteristics for the benchmark design were a 150 ha catchment, 50 ha assigned irrigation area, an irrigation system with 75% efficiency, and a clay soil with 126 mm plant available soil water within the top 900 mm of the soil profile. Three OFWS capacities were considered, namely 10, 30 and 50 ML. Rainfed and fully irrigated (‘unlimited’) designs were also simulated for comparison purposes.

The analyses are based on a representative cropping cycle for the Bundaberg region, in which the cultivar Q124 is planted on September 1 to a depth of 150 mm. This plant crop is harvested on September 20 of the following year. Subsequent ratoon crops are harvested over the next four years on days 248, 232, 227 and 217, respectively. Crop residues are retained after each crop with full incorporation to a depth of 400 mm at final harvest. Nitrogen fertiliser rates were set to be non-limiting for crop growth.

Water for irrigation is obtained from the Burnett river scheme, with the allocation period set from July 1 to 30 June of the following year with no carry-over of unused allocation water allowed. OOA within this scheme is made available when the daily flow rate over the Burnett river barrage exceeds 2400 ML for a minimum period of seven days (Darrel Griffiths pers. com.). Each system design described above was simulated over a 40-year period, using Bundaberg GPO weather station data and river flow records from 1957 to 1997.

Table 3-1 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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFWS construction cost</td>
<td>$2500/ML (10ML), $2000/ML (30ML), $1500/ML (50ML)</td>
</tr>
<tr>
<td>OFWS pump and underground works costs</td>
<td>$20000</td>
</tr>
<tr>
<td>Pumping cost (scheme to OFWS)</td>
<td>$25/ML</td>
</tr>
<tr>
<td>Water charges1</td>
<td>$38.76/M</td>
</tr>
<tr>
<td>Cost of installing reticulation equipment2</td>
<td>Nil</td>
</tr>
<tr>
<td>Sugar price</td>
<td>$300/t (assumed constant)</td>
</tr>
<tr>
<td>CCS</td>
<td>14.3</td>
</tr>
<tr>
<td>Discount rate (opportunity cost of capital)</td>
<td>6%</td>
</tr>
<tr>
<td>Operating cost for reticulation3</td>
<td>$41/ML</td>
</tr>
<tr>
<td>Other variable production costs4</td>
<td>$712/ha</td>
</tr>
<tr>
<td>Fixed production costs5</td>
<td>$14 750</td>
</tr>
</tbody>
</table>

1 Current scheme water charges for allocation and OOA.
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.
grower’s own funds. Borrowed funds repayments are therefore not included in the net income calculation.

**Biophysical Considerations**

In the absence of an OFWS, the combined irrigation from the allocation and OOA sources (195 ML averaged across the 40-year simulation) met ~50% of the irrigation demand under unlimited conditions (393 ML). The addition of OFWSs 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 3-3 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 100 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 (maximum minus minimum) 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.

**Economic Considerations**

**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’ (ie. benchmark) design. For a cane grower, the investment in an OFWS is acceptable when, subject to budget constraints and other relevant conditions, the NPV is positive.
Discounting is a calculation that converts future cash flows into present-day values to enable a sum of money received today to be compared with a sum of money received in the future. This process captures an investor’s time-preference for money, i.e., a dollar received today is worth more than a dollar received in five years’ time. 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 NPVs to be generated by calculating NPVs of OFWS investments with different starting years. Using forty years of data, it was possible to calculate 20 NPVs for each of the three OFWS-based systems for this Bundaberg case study. NPV cumulative distribution frequency plots (not shown) were prepared for each sugar price/OFWS capacity combination. From these plots, NPV values corresponding to 25, 50 and 75% probabilities were estimated (Table 3-2).

All storage capacities have positive NPVs and can be viewed as positive investments based on the variables specified in the analysis. NPVs for the 50 ML OFWS were always the largest of the three storage capacities, and hence this storage size appears to be the best investment option. Falling sugar prices significantly depressed the range of NPVs achievable for each design (Table 3-2). Such sensitivity testing of the investment is particularly pertinent in the current period of low sugar prices facing Australian sugar producers and serves to demonstrate the advantages of a modelling approach.

**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 are displayed over the 20-year investment period from 1977-1996 in Figure 3-4.
These cash flows commence in the year after the purchase of the storage. This particular investment period generated the highest NPVs of $32 091, $68 145 and $96 884 for the 10 ML, 30 ML and 50 ML OFWS-based systems, respectively.

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 1989 and 1992 can be attributed to high rainfall in these years (1609 mm and 1530 mm, respectively) and, hence a reduced reliance on irrigation. Similar insensitivity was apparent in 1983 (1323 mm rainfall) but the net income was much lower. This is attributed to the poor distribution of rainfall in this year, with over 50% of the seasonal total falling in just eight days, resulting in substantial OFWS inefficiency (across all capacities) due to overflow losses.

Environmental considerations

Tailwater recycling, deep drainage and nutrient leaching are some of the more critical environmental issues that need addressing when installing and managing any form of irrigation, including OFWS based irrigation systems. Figure 3-5 shows deep drainage cumulative distribution frequency plots for the various farm systems considered in the Bundaberg case study. These curves show typical trends with the least amount of water draining from the water limited rainfed conditions, and increasing amounts of water draining from the wetter systems.

What is somewhat counter intuitive however, is the nitrate leaching results shown in Figure 3-6. These results show that the least amount of nitrate leaching occurs with the larger OFWSs and fully irrigated systems, and that most nitrate leaching occurs in the rainfed systems, where lack of water limits crop growth. The reduction in crop growth will result in less nitrate uptake by the crop as compared with the ‘wetter’ treatments, allowing accumulation of nitrate in the soil profile, and enhanced leaching during subsequent rainfall events. Similar results have been reported previously by Verburg et al. (1996) and highlight the need to adjust nitrate fertilization rates to match irrigation management practices and crop needs.

These results also highlight the value of tools such as Dam Ea$y that allow assessment of both economic and environmental implications of alternative irrigation management practices,
and suggest that greater effort needs to be invested in evaluating these findings under field conditions. Reasons for this are that the simulation analyses presented here represent efficient irrigation strategies where differences in the nitrate leaching response are associated with differences in nitrate uptake by the crop. It is possible that high frequency and/or inefficient irrigation practices, implemented within the ‘wetter’ systems involving larger OFWSs could lead to increased deep drainage and increased nitrate leaching.

Conclusion and future developments

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 of such an investment. 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 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. Dam Ea$y cannot provide the ‘ultimate solution’. It can, however, serve 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.

This work is a good example of integrated, participatory research in which CRC Sugar has brought together the required models and a team of researchers from diverse disciplinary backgrounds, to develop a toolkit for addressing complex environmental, system design, and economic questions relating to OFWS based production systems. Dam Ea$y has been developed in close consultation with an industry partner, which it is felt will ensure its long-term relevance and applicability to the sugarcane industry.

Issues that need attention as Dam Ea$y is further developed and applied include:

- Incorporation of an ability to deal with a range of OFWS designs and engineering aspects. There is a need to accommodate variations in OFWSs ranging from in-stream dams to above ground ‘turkey nests’
- Development of databases for a range of crops and/or regions that take into account conditions specific to those regions and/or crops
- A user friendly and practical methodology for enabling Dam Ea$y to be used to address economic and environmental tradeoffs
- A version of Dam Ea$y with the ‘real time’ biophysical model coupled to the ‘real time’ economic model to provide improved analysis and fine tuning of individual situations. This will become more feasible as computing power increases
- Training and accreditation of Dam Ea$y ‘operators’. The aim is to have accredited extension officers and/or agribusiness consultants use Dam Ea$y to help individual farmers and irrigators with the application of Dam Ea$y and interpretation of results obtained. This will maximise the power of Dam Ea$y while providing input to farm specific issues
- Ongoing ivalidation. There are currently no simple methodologies to ground truth
complex models like Dam Ea$y, so testing, evaluation and ongoing improvement will therefore need to be an integral part of Dam Ea$y’s evolution

- Estimates of salt accumulation within the soil and on-farm storage associated with evaporation and evapotranspiration

Apart from on-farm issues addressed in this paper, there are also broader scale irrigation scheme/catchment scale issues that need addressing. OFWSs add ‘capacitance’ into the overall water supply system, and the total capacitance and its impacts will depend on how many OFWSs are added and on how they are managed. Incorporation of Dam Ea$y or similar models into a larger catchment scale model will allow assessment of the likely impacts of OFWSs on whole of system water balances (including groundwaters and river flow patterns), and the development of more effective catchment scale integrated water management guidelines.

References


Introduction

Queensland sugar towns produce over 60,000 ML of secondary treated sewage effluent each year (Bryant et al. 1994) which, if used for irrigation, has the potential to produce over 700,000 tonnes of extra sugar cane each year (assuming 1 ML of irrigation produces 12 tonnes cane; Kingston 1994). With the increasing pressure by the Environmental Protection Authority on local authorities to either upgrade the quality of their sewage effluent to tertiary standards (a capital intensive option — Keller & Hartley 1997) or cease its discharge to rivers and estuaries, there is an opportunity for communities in rural areas to turn this problem into a win/win situation, by reusing secondary treated effluent for crop irrigation. This option is particularly attractive in sugar towns where the closely settled nature of the industry presents modest pumping distances (eg. < 20 km) and the high water consumption of cane ensures modest to high irrigation demand in even tropical North Queensland (Robertson et al. 1997).

Moreover, because sugar is a processed product involving high temperatures and crystallisation in its manufacture, the health risks from ingesting sugar from effluent irrigated sugar cane are minuscule compared with the risks from say effluent irrigation of salad crops that are eaten raw (Gardner et al. 1998).

There are a number of major issues associated with the safe, environmentally sustainable reuse of sewage effluent, and these include human health risks, irrigation schemes, hydrology and economic aspects. Human health risks associated with the microbiological quality of effluent, and the method of effluent application have been discussed elsewhere (Rynne et al. 1998, Vieritz et al. 1998a).

The hydrology of irrigation schemes is one of the key issues that determine environmental sustainability. The successful operation of effluent reuse schemes depends largely on getting the correct combination of wet weather storage volume (ML) and irrigation area (hectares) for a given effluent production (ML/year) to ensure a low frequency of pond overtopping, and a high reliability of effluent irrigation supply. These performance criteria must also be achieved at the lowest practical cost. In this paper we present a brief overview of the design tools available for the irrigation-agronomy components and apply these tools to a case study taken from south-east Queensland.

The economic aspects of effluent irrigation often generates the most debate as both the effluent producer (a local authority) and the potential effluent consumer (eg. cane farmers) believe they are each doing the other a major favour. And the recipient of this favour should bear the major cost of the irrigation scheme. If we now introduce the concept of community savings by deferring expensive sewage treatment plant (STP) upgrade to tertiary levels, and a mix of subsidies from local and commonwealth authorities for STP upgrade or reuse scheme construction, identifying fair partitioning of costs and benefits becomes very complex.

To assist in this important community, industry and environmental debate, we have developed the spreadsheet model SUGARCOST to perform financial evaluation of effluent irrigation by comparing the benefits to local authorities in deferring sewage treatment plant upgrade and subsidising effluent irrigation schemes vs the benefits and cost to sugar cane growers in investing in effluent irrigation infrastructure. The methodology developed is logical, transparent and reproducible, allowing...
an informed debate between all the stakeholders in a reuse scheme (including the State Government). In this section we describe the structure of SUGARCO$T, the input data required and illustrate its application to a sugar reuse scheme in south-east coastal Queensland.

**Irrigation Hydrology Design Tools**

Daily time step biophysical models are proving invaluable in providing good estimates of irrigation demand, taking into account the interaction between climate, crop growth and soil type. Irrigation demand, along with wet weather storage volume, are central to the success or failure of an effluent irrigation scheme of given effluent supply.

The irrigation demand — crop yield response predictions for reuse schemes involving sugar cane in different locations have been calculated using the daily time step crop growth model APSIM — Sugarcane (Keating et al. 1999). The major advantage of APSIM Sugarcane is its ability to incorporate the effects of sugar cane agronomy, such as plant vs ratoon cane, pre-harvest drying down period, and soil nutrition etc on canopy development, and hence the amount and timing of irrigation requirements, and translate this into a predicted irrigated sugar yield.

The interaction between effluent supply, effluent storage, crop demand and climate variability was captured by adding into APSIM Sugarcane the lagoon water balance algorithms from the effluent disposal model MEDLI (Gardner et al. 1996).

Table 4-1 shows the average results for a 40 year simulation run under dryland and fully irrigated conditions for a range of sugar towns along coastal Australia. Predicted irrigation demand varies from 470 mm/year to 780 mm/year, yet the variation is not always explained by rainfall. Apart from the substantial annual irrigation demand for all locations (including Cairns), the modelling has identified some non intuitive results such as the similar irrigation demand for Mackay (490 mm/yr) and Grafton (470 mm/year), which has 700 mm less rain per year, but similar potential crop water use (about 1100 mm / year).

One of the main reasons for the high yield / low irrigation demand at Mackay is its (relatively) small vapor pressure deficit (which APSIM uses to scale the Water Use Efficiency factor which converts biomass into water use).

In terms of maximising water use to minimise the area of irrigated cane, Ingham is the preferred location (781 mm / yr irrigation demand) closely followed by Maryborough (707 mm / year).

Once the potential irrigation demand for a scheme is determined it must be combined with irrigation area and wet weather storage to predict hydrological behaviour. Figure 4-1 shows the effect of various area-volume combinations on overtopping volumes for a 2900 ML / year effluent reuse scheme in southeast Queensland, using 20 years of climate data. As the irrigation area increases from 120 ha to 270 ha there is a sharp decline in overtopping volume for all wet weather storage volumes (100 to 900 ML). This effect is

<table>
<thead>
<tr>
<th></th>
<th>Cairns</th>
<th>Ingham</th>
<th>Mackay</th>
<th>Maryborough</th>
<th>Grafton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dryland Cane fresh weight (t/ha)</td>
<td>106</td>
<td>100</td>
<td>126</td>
<td>95</td>
<td>110</td>
</tr>
<tr>
<td>Irrigated Cane fresh weight (t/ha)</td>
<td>171</td>
<td>177</td>
<td>183</td>
<td>174</td>
<td>162</td>
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<tr>
<td>Average rainfall (mm)</td>
<td>2028</td>
<td>2037</td>
<td>1734</td>
<td>1117</td>
<td>1050</td>
</tr>
<tr>
<td>Effective rainfall (mm)</td>
<td>712</td>
<td>741</td>
<td>628</td>
<td>655</td>
<td>654</td>
</tr>
<tr>
<td>Average Class A pan evap (mm)</td>
<td>2130</td>
<td>2180</td>
<td>1980</td>
<td>1640</td>
<td>1650</td>
</tr>
<tr>
<td>Average irrigation demand (mm)</td>
<td>602</td>
<td>781</td>
<td>493</td>
<td>707</td>
<td>474</td>
</tr>
<tr>
<td>Crop water use (mm)</td>
<td>1314</td>
<td>1522</td>
<td>1120</td>
<td>1362</td>
<td>1038</td>
</tr>
</tbody>
</table>
far more important than the reduction in overtopping volume with increased storage volumes, for any of the chosen irrigation areas (120 ha to 700 ha).

As this overtopping volume is secondary treated sewage effluent, a discharge license has to be negotiated with the EPA on the basis of volume per year (eg. 10% of effluent production) or frequency of overtopping (eg. five events per ten years). This will be a location specific negotiation depending on the assimilative capacity and environmental sensitivity of the receiving environment. Most of the coastal sewage treatment plants in Queensland discharge into tidal rivers, whilst most of the effluent volume is discharged into river mouths or estuaries (Bryant et al. 1994).

Figure 4-2 shows the effect of irrigation area and wet weather storage volume on the reliability of irrigation supply, defined as the percentage of irrigation demand met for unrestricted water supply (average irrigation demand for this location is 700 mm/year). This is the hydraulic performance criterion, which is of most interest to farmers.

The irrigation reliability percentage encapsulates the effect of year to year variation in effective rainfall, where in dry years, there is insufficient effluent volume to completely supply the above average irrigation demand, despite withdrawals from the wet weather storage of effluent carried over from previous (above average) rainfall years.

The major sensitivity is to irrigation area with a substantial reduction in reliability as the area increases from 270 ha to 540 ha. The initial gain in the reliability of supply with increasing storage size for a given irrigation area can be attributed to a substantial decline in overflow (or wet weather spillage) (Figure 4-1). Eventually the storage gets to a size where overflow losses are minimal, and irrigation reliability is primarily restricted by the supply of effluent.

A similar calculation can be presented for cane yield response, but because of the strongly coupled nexus between water use and yield in the APSIM model, the form of response is very similar to that in Figure 4-2.

It is clear that there is a convergence between low overtopping volume and high irrigation reliability as wet weather storage volume increases, but a divergence between these two outcomes as irrigation area increases. Multiple runs using optimisation techniques in models such as MEDLI (Gardner et al. 1996) can establish an area — volume domain where both irrigation reliability (eg. 80%) and spill volume (eg. 10%) criteria are fulfilled and then identify a generic minimum cost area — volume combination, (Vieritz et al. 1998b) but this facility is not available in the APSIM Sugarcane model. We do not believe that this is a severe limitation for this section as the main objective of Figure 4-1 and Figure 4-2 is to demonstrate the nature of the interaction between storage volume-irrigation area on overtopping.
behaviour and irrigation reliability.

For complete scheme designs, calculating the frequency of overtopping, (eg. 1 event per 10 years or 5 events per 10 years, or the volume of precautionary discharge from storage) is often required by regulatory authorities, and this will require a more rigorous analysis than shown in Figure 4-1. Later in the text we will use SUGARCOST to describe the economic aspects of a 700 ML — 740 ha reuse scheme under construction in south-east Queensland which falls within the volume-area bounds shown in Figure 4-1 and Figure 4-2.

Economic analysis using SUGARCOST - its structure and assumptions

SUGARCOST can be used to assess the costs and benefits of sugarcane effluent irrigation schemes by inserting appropriate values for many user-defined biological, physical and financial variables. Although equipped with a large set of default data, most of the variables should be user-defined because many costs are highly specific to the scheme being examined. Operators of SUGARCOST should therefore have basic design information of the proposed scheme. Similarly, while SUGARCOST can be used to analyse the profitability of irrigated effluent schemes stand alone, it should be used in conjunction with APSIM and MEDLI to obtain data on the yield response to applied irrigation rates associated with various storage volume / irrigation area combinations.

The basic structure of SUGARCOST is a series of linked Microsoft Excel Spreadsheets containing data for effluent storage and distribution, STP upgrading options, on-farm costs, and financial evaluations. Features of these are discussed below.

'STP to Farm' Infrastructure Costs

The “STP to Farm” section of SUGARCOST calculates capital and operating costs associated with pumping effluent from the STP to a storage near the cane area to be irrigated, and pumping effluent from the storage via a network of pipelines to the cane farms as required. It is assumed that these costs, principally associated with storage construction, pumps and distribution pipeline, are incurred by the local authority, unless otherwise specified by the user. In this section of SUGARCOST, provision has been made for the user to nominate alternative sources of funding for the infrastructure, including government subsidies and contributions to the scheme from cane growers.

Costs for storage pond construction depend on the volume of the effluent storage. The storage requirement is determined from the biophysical modelling using APSIM (and MEDLI) according to percent effluent reuse and frequency of overtopping criteria and crop water use. The costs of building a storage pond is represented by a default value, or a built in calculator, however users may elect to enter their own estimate of storage construction cost ($/ML). Likewise, for pump and pipeline costs, SUGARCOST users may enter their own estimate of pump and pipeline costs or use the built-in calculator which estimates pump/pipe cost from a set of user-defined physical specifications including pipeline distance, static lift, flow rate, pressure and hours of pump operation.

Annual scheme maintenance costs are estimated as percentages of capital costs, whilst pump operating costs are calculated in the add-in pump/pipeline calculator. Other costs such as land acquisition, environmental monitoring, application fees for license and ongoing annual license fees can be estimated by the user and input into the spreadsheet.

Cane production

The “Cane Production” sheet compares the costs and benefits of effluent-irrigated cane production with those associated with dryland cane production. The user is required to enter details about the irrigation scheme, including the whole scheme irrigated area, the number of farms in scheme, irrigation applied (ML/ha), the cane yields for irrigated and dryland production, and the type of irrigation system installed.

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1 The pump/pipeline cost calculator supplied with SUGARCOST has been developed by FSA Environment P/L
Irrigation capital costs can be specified as either being incurred in full at the time of purchase or expressed as an annuity, which represents an annual repayment on borrowed funds. The spreadsheet also accounts for fixed overhead costs (e.g., insurance, registrations) and variable production costs or “cash costs” (e.g., fertiliser, crop chemicals, fuel and lubricants). Additional costs associated with operating irrigation equipment are specified separately. These include electricity for pumps, repairs and maintenance for irrigation equipment, and hire of additional labour. The additional harvesting cost incurred as a result of higher yields is calculated in the spreadsheet. Grower contributions to scheme capital costs and/or operating costs are carried over from the linked “STP to farm” spreadsheet and added into the assessment of cane production costs.

Gross income for both irrigated and dryland production is calculated, based on the cane payment formula. The sugar price and CCS for irrigated and dryland cane production are user-defined variables. The spreadsheet calculates net profit before interest and tax per farm. In a later section, the sensitivity of the calculation to sugar yield and price is explored.

**STP upgrade**

The decision to set up an effluent irrigation scheme will be influenced not only by the potential profitability of using effluent for irrigation, but also on the comparative profitability (or net costs) of alternative re-use options. Tertiary sewage treatment involves a high level of nutrient removal and is an alternative to effluent irrigation. SUGARCO$T conducts financial evaluation for three STP upgrade options to tertiary treatment:

- Upgrading activated sludge plant to reduce N by biological treatment and P by chemical treatment.
- Upgrading activated sludge plant to reduce N and P by biological treatment.
- Installing a new BNR (Biological Nutrient Removal) plant (bio P and bio N).

The cost of upgrading STPs was obtained from a number of sources (Hartley 1998; Ken Hartley, pers. com., Geoff Hamilton, Gold Coast City Council, pers. com., Sonja Komarowski, Redland Shire Council, pers. com.). Estimates of capital and annual operating and maintenance costs are provided for a range of upgrade options in SUGARCO$T.

The costs to upgrade STPs depend on the type of plant and equipment already in operation, the volume of effluent treated, the nutrient concentration present after secondary treatment and the target level of nutrient after tertiary treatment. Because so many variables affect the costs, the values calculated in the spreadsheet should be used only as a guide.

**Financial performance**

Annual cash flows and net present values (NPVs) are calculated for both the Local Authority incurred costs (covering the investment in irrigation scheme infrastructure), the on-farm costs, and the benefits of using effluent for irrigation. For the NPV calculations, only the additional cash flows directly related to the reticulation of effluent for producers (local authorities) and consumers (cane growers) have been included in the model. Likewise, only additional costs involved in the alternative upgrading options are considered. The spreadsheet is currently configured for a ‘base case’ of dryland cane production. However, alternative base cases, such as farm with existing irrigation equipment and a limited supply of irrigation water, may be considered. From the local authority’s perspective, the ‘base case’ in SUGARCO$T is discharge of secondary treated effluent to waterways using existing STP treatment.

A discounted cash flow approach over a 20 year period can be generated for two capital payment options: a) use of own funds for up-front purchase of capital b) use of borrowed funds repaid over the full life of the project. The discounting procedure captures the opportunity cost over time that is associated with the resources tied up in the purchase.

A key assumption in the current version of the spreadsheet is that the costs and benefits remain constant over the life of the project. This means that unit prices and costs move in line with changes in the rate of inflation, and that there is no yield or sugar price variability from year to year.
Economic analysis - Case study

The same case study of a southern Queensland regional sugar town described in Figure 4-1 and Figure 4-2 was also used to explore the returns (and savings) to council and cane growers by commissioning a reuse scheme, thereby deferring STP upgrade. The assumptions we used were taken from the scheme design undertaken by an engineering consultant (Table 4-2).

Compared with the modelled output, the existing scheme design has a much larger irrigation area (740 ha I 270 ha) and a considerably smaller irrigation application (3†ML/ha/yr vs 7 ML/ha/year).

Whilst the volume-area combination chosen by the scheme consultants minimises overtopping volume (Figure 4-1) the resulting lower amount and reliability of irrigation supply (Figure 4-2) has meant that the irrigated yields we used were adjusted downwards to 120 tonnes cane/ha (vs 174 t/ha predicted; Table 4-1).

The sugarcane production economics are based on a representative farm for the southern Queensland cane production region. Typical production costs for the representative farms were sourced from Canegrowers (1997) and ABARE (1997). Revenue from cane sales was calculated using a sugar price of $320/t and a CCS (commercial cane sugar) of 12. Capital and operating costs for a winch irrigation system were included. It was assumed that the representative cane farm did not have an existing irrigation reticulation system.

It is assumed that local authorities and consortium of growers participating in the scheme have negotiated a cost-sharing arrangement that involves cane growers contributing to the infrastructure capital and operating costs associated with delivering effluent from the central storage to the farms. For this case study, this comprises a contribution to the capital cost of the scheme collected through a $10/ML levy over 20 years. In addition, growers also fully pay for the operating and maintenance costs of the scheme through a $/ML payment.

The local authority is eligible to claim a State Government (Department of Communication and Information, Local Government, Planning & Sport) subsidy of 50% contribution towards the capital costs of the irrigation scheme. A 40% subsidy can also be claimed towards the cost of

<table>
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<tr>
<th>Table 4-2: Assumptions used in case study</th>
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<tr>
<td>Effluent Volume</td>
</tr>
<tr>
<td>Storage Volume</td>
</tr>
<tr>
<td>Irrigation Area</td>
</tr>
<tr>
<td>Number of Farms</td>
</tr>
<tr>
<td>Dryland Yield</td>
</tr>
<tr>
<td>Irrigation Yield</td>
</tr>
<tr>
<td>Irrigation Applied</td>
</tr>
<tr>
<td>Pipeline length (to storage)</td>
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<tr>
<td>Pipeline length (from storage to farm)</td>
</tr>
<tr>
<td>State Government Subsidy</td>
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<tr>
<th>Table 4-3: Additional annual costs and benefits to local authorities and growers associated with investment in an effluent irrigation scheme.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benefits per year</td>
</tr>
<tr>
<td>Local Authority</td>
</tr>
<tr>
<td>– grower contribution to scheme collected through $10/ML levy.</td>
</tr>
<tr>
<td>Individual cane grower</td>
</tr>
<tr>
<td>– revenue from additional cane production of 40 t/ha.</td>
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upgrading an STP from secondary to tertiary treatment, which will allow continuing discharge of effluent to water bodies.

Table 4-3 shows the additional annual costs and benefits to local authorities and growers from investment in an effluent irrigation scheme. Annual costs and benefits have been incorporated into a discounted cash flow analysis to estimate the value of the investment over a 20-year period. Net present values were calculated using a 7% and 10% discount rate (Table 4-4).

**Grower benefits**

On the basis of this case study, investment in effluent re-use for irrigation is worthwhile for a canegrower. The additional annual profit (before interest and tax) compared with dryland production is approximately $17 000 (i.e. $49,900-$32,900 Table 4-3). Over 20 years, the net present value for a 7% discount rate is $205 003 per farm (Table 4-4). The combined NPV for the 14 farms in the scheme amounts to $2.87 million net benefit (Table 4-4). These numbers, as expected, reduce for a 10% rate but the returns are still very favourable.

NPV is highly sensitive to changed sugar prices and yield increases attributable to effluent irrigation (Table 4-5). With a projected yield increase of 40t/ha, NPV is 2.5 times higher if the sugar price obtained increases from $270/t to $370/t. However, the investment in effluent irrigation from the growers point of view would not be worthwhile if a below-expected yield increase of only 20t/ha was achieved, combined with a $270/t sugar price over the investment period (Table 4-5). The sensitivity analysis is pertinent in the current period of low sugar prices being experienced by the sugar industry. The sensitivity analysis highlights the importance of considering long term information about sugarcane yields and commodity prices because they have such a significant impact on the financial viability of the investment.

**Council — effluent irrigation vs STP upgrade**

From the local authority view, investment in an effluent irrigation scheme appears more economically attractive than replacing the STP with a tertiary treatment BNR plant. While neither option generates a positive NPV (Table 4-4), if faced with having to make a choice between the two options, the local authority would be better off by $11.4 million at a 7% discount rate by deferring STP upgrade and investing in an effluent irrigation scheme (Table 4-4). The savings reduce to $10.3 million when a 10% discount rate is assumed.

Effluent re-use schemes can clearly benefit both
local authorities and cane growers. SUGARCO$T presents an opportunity for both parties to negotiate for a share of these savings.

An important component of this financial analysis is regulatory permission to discharge secondary treated effluent into waterways during extended periods of wet weather. In wet coastal climates it may only be practical to reuse 80-85% of annual effluent production, because the wet weather storage acts as net rainfall accumulator (i.e. rainfall input exceeds evaporation losses). Hence increasing storage size actually increases the volume of effluent required for reuse/disposal.

The NSW Environment Protection Authority (1995) recognises this issue to some extent and allows the average frequency of overtopping to increase as the nutrient and BOD concentration of the effluent decreases. This approach is also consistent with their load based licensing philosophy.

A corollary to this approach is precautionary discharge, which is controlled effluent discharge into receiving waters that are made only under set conditions, which include the effluent discharge rate, the river flow rate and storage level in the wet weather storage (Pettit and Murtagh 1999). The objective is to achieve a minimum (effluent) dilution rate in the river. Other site specific criteria can apply, such as faecal coliform concentration.

In New South Wales the EPA (P. Marczan, pers. comm.) will also require effluent that is discharged either continuously or above a certain frequency, to meet effluent discharge criteria. These criteria are determined on a case by case basis taking into account the water quality objectives for the receiving water and the requirements of The Protection of the Environment Operations Act 1997. For example, in inland waterways effluent will often be required to have nutrient levels of $N \leq 10 \text{ mg/L}$ and $P \leq 0.3 \text{ mg/L}$, 90% of the time.

In this case, tertiary treatment of the effluent will almost certainly be required, and could remove some of the economic benefit to council of deferring STP upgrade (Table 4-4 — Council Option 2). However, in New South Wales, incentives are also provided in the form of up to a 100% reduction in the pollutant load component of license fees for that portion of the effluent that is reused. This approach has encouraged a strong move towards effluent reuse in major country towns such as Albury, Mudgee, Narrabri and Armidale (P. Marczan, pers. comm.).

In Queensland, the EPA advises (L. Bevis, pers. comm.) that the discharge of secondary treated effluent from sewage treatment works to waterways, including wet weather releases, are negotiated on a case by case basis in accordance with the requirements of the Environmental Protection Policy (Water) 1997 (EPP Water).

Clearly SUGARCO$T has the potential to influence government policy to increase the economic attractiveness of sustainable reuse options particularly as it is a more preferred disposal option than releases to surface waters, and in line with the philosophy of the EPP Water.

**Conclusion**

The sugar industry is well placed to use sewage effluent as an irrigation source and increase cane yields by over 700,000 tonnes per year. SUGARCO$T demonstrates that even under current cost sharing arrangements with local authorities, effluent irrigation is likely to be economically (and socially) worthwhile. The model has also identified the potential for effluent irrigators to gain a share of the savings captured by urban rate payers from deferring the upgrade of STPs to tertiary standards. This economic argument disappears, however, if Local Authorities are forced into tertiary treatment by regulatory or other types of community pressures without other incentives being in place.

A remaining challenge for the sugar industry is to ensure that secondary treated effluent can be irrigated without endangering the health of farmers, their families or the public at large. This will require a combination of good effluent disinfection practices and care in the method of effluent application (eg. spray vs furrow vs drip) (Gardner et al. 1998, Rynne et al. 1998).
References


Introduction

Unfavourable consequences of modified land use practices include nutrient enriched waters, a greater likelihood of algal blooms and unwelcome changes to ecosystem composition and health. These concerns extend to the sea, where land-based sources of nutrients, toxicants and sediments can impact adversely (e.g., Kelleher 1988; Furnas et al. 1995; Zann 1995).

Both point-source and diffuse or non-point sources are responsible for lowering the quality of natural waters. Licensing and regulation has controlled the former reasonably effectively (Moss and Bennett 1991). In contrast, non-point sources of water pollution from rural and urban lands are more difficult to control, even though adverse impacts on water quality are usually greater (OECD 1986), primarily due to the much larger areas involved.

The focus of this chapter is on land to water losses that impact on water quality, dissolved oxygen, strongly acidic water, and benchmarks of surface water quality in cane growing areas. Pesticides and groundwaters are covered elsewhere.

Land use “pressure”

Sugarcane is grown in 29 major river catchments in Queensland and NSW. Twenty-eight of these drain to east coast waters, including Moreton Bay, the Great Sandy Region and the Great Barrier Reef World Heritage Area. The Mitchell drains to the Gulf of Carpentaria. Only in seven catchments [Mossman (10.0), Mulgrave/Russell (13.1), Johnstone (14.8), Haughton (10.4), O’Connell (11.1), Pioneer (17.9), Plane (21.0)] does sugarcane occupy ≥10% of the total catchment area. Sugar cane occupies < 5% of 15 of the remaining river catchments including about 0.3% of the Burdekin Catchment and 0.41% of the Clarence Catchment. At an average of ≈1.5% of the total land area of the 29 catchments, it follows that land uses other than sugar, particularly during major run-off events, will have the dominant influence on river water quality, in-stream sediment loads, nutrient fluxes, and discharges to the sea. (Anon 1993a, Rayment & Neil 1996, Rayment 1999). On a unit area basis, however, cropping lands can make a disproportionate contribution to in-stream loadings (higher contribution; Moss et al. 1993), and there is evidence (Hunter and Walton 1997; Bramley and Roth 2001) that more labile forms of nutrients such as nitrate are associated with these discharges.

Statistics compiled by Pringle (1991) for the periods 1897, 1944-45, and 1983-84, show progressive increases in total areas being cropped in coastal Queensland. This expansion can be expressed numerically as increases in potential stream sediment yields. For the Tully Catchment since 1866, negligible increases due to cane occurred to 1885 but there was a 20% increase from 1924-31. Corresponding increases due to cane or cane and bananas combined for periods 1931-58 and 1967-90, respectively, were 31 and 13% (Neil 1994, 1995). A trebling in the area under cane in Queensland occurred during the period 1951 to 1988 (Pulsford 1991), with a further increase of over 40% in the last decade (CANEGROWERS 1999). Such expansions add to pressures on local and downstream water quality.

Land to water movement

Unit suspended sediment yields based on
measured data from the Barron River, Babinda Creek, Tully River, Herbert River, Burdekin River and headwaters of the Flinders River range from 29 to 94 t/km², with a strong influence of vegetation cover (lower when vegetation cover is high). Sediment yields of lands under cropping almost always increase by a factor of 10 or more, when compared to natural catchment yields. Estimates of increase factors for the Tully River and the Banyan Creek Sub-catchment were about 15 and 30 during cyclone Ivor, with factors closer to 20-25 likely to be applicable to the majority of Queensland coastal streams (Neil and Yu 1996) during major flow events.

Ignoring the remobilisation of in-stream sediments, soil erosion driven by irrigation and rainfall events, and the collapse of stream-banks during periods of high stream flows, are the major sources of suspended sediments to streams (Rayment and Neil 1996). For example, annual soil losses in row crop sugarcane in the Johnstone River Catchment of from <50 to 500 t/ha (average of 150 t/ha) have been measured (Prove 1988; Prove et al. 1995). Under lower rainfall conditions near Mackay, annual soil losses were reported at 42 to 227 t/ha (Sallaway 1979). These losses have now being lowered dramatically to <5-15 t/ha/yr by moving cane assignments to erosion-resistant lands, the implementation of soil conservation plans, and by green cane trash blanketing (GCTB) (Sullivan and Sallaway 1994; Hardman et al. 1985). Soil loss rates as low as 1-4 t/ha/yr are possible with GCTB and zero tillage. As the nutrient enrichment ratio of water-eroded soil generally decreases as sediment yield increases (Rose and Dalal 1988), the lesser quantities of sediment in runoff from zero tilled and trash blanketed cane fields can be partly off-set by higher nutrient and heavy metal enrichment.

Information on run-off susceptibility classes for bare and covered canelands is lacking in most areas but is available for soils of the Lower Herbert. The highest likelihood of run-off generation and hence the greatest threat of riverine P (and N) is expected to the north of the Herbert River in the Ripple Creek sub-catchment and in lower parts of the Stone River catchment. Some of the lowest run-off incidence is expected on well-drained levy soils of the Herbert, although such soils are sensitive to loss of mobile nutrients (nitrate) by leaching (Bramley et al. 1998; Bohl and Roth 1999). Caution is needed, however, as gully erosion can be more important than land use in the off-site movement of P to streams (Neil and Fogarty 1991; Donnelly et al. 1996).

Despite the unequivocal need for nutrient additions in almost all modern agricultural production systems, research findings have confirmed positive correlations between fertiliser use and nutrient movements to waterways and groundwaters (Garman 1983; Addiscott et al. 1991). Sediments derived from soil erosion and runoff are both a sink for nutrients and a possible water quality hazard.

Modelling has pointed to rangelands as the major source of suspended sediments and nutrients lost to the sea from Queensland’s east-coastal waters (Moss et al. 1993; Neil and Yu 1996). However, Moss et al. (1993) identified cropping lands as the source of most suspended sediments and nutrients to waterways on a per hectare basis, suggesting room for improvement at paddock and farm scales. It is estimated (G. Rayment, unpublished data) from contemporary land-use areas and Model 2 of Moss et al. (1993) that around 8,800 tonnes of N and 1,300 tonnes of P are lost annually to east-coastal waters of Queensland from canelands. These correspond to ≈ 12% each of annual N and P fertilizer inputs (2000 statistics). The total mean suspended sediment flux sourced from coastal Queensland canelands is estimated at 1.25 M tonnes annually, equivalent to ≈2.6 tonnes/ha (G. Rayment, unpublished data).

Using a balance-sheet approach, (Bloesch et al. 1997) estimated total quantities of P lost to rivers from Queensland sugar lands in 1993/94 at 1,450 tonnes. Highest losses were from Northern canelands (759 tonnes), equivalent to 4.6 kg P/ha. Corresponding loss estimates from the Burdekin, Central and Southern regions averaged 1.8, 2.3 and 2.8 kg P/ha. Despite these losses, there were net gains in P to Northern, Central and Southern cane growing regions, mainly due to fertiliser inputs and applications of mill muds (typically 150 t/ha wet weight), and a slight depletion (-0.2
kg P/ha) in the Burdekin. Indeed, there is convincing evidence of a slow, continuing upward trend of soil P fertility on 75-80% of cane farms (Rayment et al. 1998b). This trend increases the opportunity for P losses, particularly in surface runoff, although there is no guarantee that P levels in nearby stream sediments will be similarly elevated. Certainly at 40 of 43 sites in waterways of canegrowing areas in south-east Queensland, Pailles and Moody (1996) found no apparent association between the P status of canelands and enhanced P levels in nearby bottom sediments. The exceptions were at Splitter’s Creek, Tinana Creek and Bidwell Creek.

The export of suspended sediments from sugar cane areas of the Johnstone Catchment, derived from modelling of water quality monitoring data from the early to mid-1990’s (Hunter and Walton 1997) was ≈ 4 tonnes/ha/yr (75,164 tonnes/yr). Total N at 40 kg N/ha/yr (752 tonnes N/yr) partitioned as ≈ 50% in sediment, 27% as nitrate-N and 3% as ammonium-N. Corresponding P losses averaged 7 kg P/ha/yr (132 tonnes P/yr), of which 81% was sediment-bound. These losses equate to 15.9% and 17.2% of annual N and P fertiliser inputs, which averaged 4,730 and 765 tonnes annually during the five-year period 1990-1995 (Pulsford 1996, 1998). The percentages are very similar to the modelled estimates quoted earlier in this sub-section. The measured losses also concur with estimated annual mean losses from the South Johnstone River in 1990 and 1991 of 320 and 32 tonnes of total N and total P, respectively (Mitchell and Furnas 1994). Earlier, Garman (1983) estimated annual losses of P from different land uses in Australia of 0.01 kg/ha from forest/conservation areas, 0.1-0.3 kg/ha from pastures, 0.6 kg P/ha from urban areas, and 3.0 kg/ha from cropping lands.

Modelling to a range of scenarios in the Herbert River Catchment (Johnson et al. 1998) suggests 1% of the sediment yield from the total catchment was sourced from canelands, whereas 21% came from areas used for cattle grazing. In addition, caneland distribution was closely linked to “high” soluble N concentrations. The adoption of GCTB resulted in a decrease of modelled discharge and sediment yield from 1977 to 1996. Under the burnt cane system, nutrient output from individual “cells” reached as high as 3.8 kg/ha whereas under GCTB harvesting, no cell in the area produced in excess of 0.8 kg/ha of suspended sediment.

At the process level, P desorption studies indicate that with exception of heavier clay soils, the majority of river sediments derived from lower Herbert soils have moderate to large desorption risk classes between 5-10 mg and >50 mg P/kg, at a river-water P concentration of 0.05 mg P/L. Laboratory simulations using the same soils suggest that the P is much more strongly held when in marine water than in fresh river water; ie., any environmental threat posed by transport of P via eroded soil is likely to be greatest in upstream areas and least when eroded into sea water (Bramley et al. 1998).

CRC Sugar data exist for total heavy metal concentrations in canelands of Queensland and NSW on a regional and soil depth basis (Rayment et al. 1997, 1998a). Using mean data from the 0-100 mm depth interval and assuming no heavy metal enrichment in runoff, averages of 4.9, 0.06, 17, 107, 23, 0.08, 1.1, 32, 0.45, 0.20 and 61 g of As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Se, Tl and Zn, respectively, will be lost with each tonne of surface soil moved to waterways (Rayment 1999). Excluding Cu, as it was similar, reported total heavy metal concentrations in sediments from fresh-water zones of some “reference” Queensland rivers (Semple and Williams 1998), including several from cane-growing catchments, differed from those in surface soils from Queensland canelands. The median Cd concentration in sediments was 25 times higher, while total Cr, Ni, Pb and Zn were around 1.6, 1.6, 4.8, and 1.4 times lower than corresponding mean concentrations in Queensland canelands. Measurement error may account for some of the apparent differences. Given the long half-life of heavy metals in the environment (e.g., 15-1100 years for Cd, 310-1500 years for Cu, and 740-5900 years for Pb), a convincing explanation for the surprising differences in concentrations needs to be found.

**Dissolved oxygen (DO)**

Low DO concentrations have adverse effects on many aquatic organisms (e.g., fish,
invertebrates, and microorganisms) that rely on DO for efficient functioning and survival. In addition, low levels of DO promote reducing conditions that facilitate the release of nutrients such as P and metal toxicants to the water column. Limited Australian data suggest that DO concentrations < 5 mg/L are stressful to many species, while new national guidelines suggest DO "trigger values" for slightly disturbed ecosystems for lowland-rivers of 85 through to 110% saturation (low and upper limits; upper limit of 120% in tropical Australia). A lower limit of 80% saturation applies to estuaries, with upper limits as for lowland rivers (Anon 2000). One hundred percent DO saturation in freshwater free of chlorinity at 15°C equates to 10 mg/L, while concentrations of DO decrease predictably as both temperature and chlorinity increase (APHA 1998).

In addition to temperature, DO production and consumption is influenced by light intensity, direct absorption of oxygen from the atmosphere, and the normal chemical and biochemical processes that occur in all surface waters. Photosynthesis increases DO but production slows during overcast weather. Plant and microbial respiration consumes DO, as does the breakdown of organic matter following entry in runoff water and from the breakdown of aquatic plants killed by herbicide spraying or other causes. Anoxic drainage water can lower DO by dilution and by the carriage of oxygen consuming chemicals such as ferrous iron (Fe²⁺). Lowest concentrations of DO typically occur soon after dawn and at the bottom of deep pools and dams. However, this situation is complicated in tidal areas, where oceanic waters rich in DO can supplement that lost due to high respiratory activities. A pattern of changes in DO with tidal flow can therefore be expected, with lowest concentrations of DO correlating with low tides and highest concentrations with high tides.

Continuous in-stream measurement of flow and DO is a reliable way of tracking fluctuations in DO concentrations (see Figure 5-1).

Figure 5-1: Trends in daily mean dissolved oxygen, pH and discharge volume for Sandy Creek (A) and Hotham Creek (B) in the Pimpama Sub-catchment for the period Sept.-Dec 1998 (Gavine and Gardner 1999)

Typical 50th percentile “unpolluted” DO values reported for the period January 1988 to December 1991 for Queensland streams and estuaries were around 85-90% saturation. At that time, most of the 10th percentile DO values were in the immediate vicinity of treated sewage discharges. They sometimes were believed to reflect storm events that transferred organic matter to the waterbody (Anon 1993b).

A recent example (Wilhelm 2001) of 5-yearly trends in DO at 18 sites nearby to sugarcane in coastal Queensland for the period 1st May
1995 to 30th April 2000 has shown that the lowest levels (< 5 mg/L) were detected in the Plane, Burrum (Elliott River) and Maroochy catchments. Importantly, the majority of sites were within 1992 ANZECC guidelines (ANZECC 1992) for DO most of the time.

Moss and Bennett (1991) reported that five-day biological oxygen demand (BOD5) associated with cooling water discharges containing sugar juices and vapours can reach values of 20-100 mg/L. They noted that the coincidence of the sugar crushing season with North Queensland’s (usually) dry winter months exacerbates DO depletions and supports the need for proper management of mill discharges. They further noted that during wetter months, organic loads washed in from the catchment might significantly lower DO levels. Brodie (1991) also observed that sugar mill wastes had high BOD values and reported that fish kills were associated with the release of such wastes into coastal streams. Strong DO depletion has also been measured in waterways draining established cane growing areas in the Burdekin River Irrigation Area (Congdon and Lukacs 1996).

In the super-wet, cane harvesting season of 1998 (estimated reoccurrence intervals of >>100, >15 and >60 years for Mackay, Burdekin and Ingham, respectively; Max Winders & Associates 1998), there were unprecedented numbers of documented fish kills in North Queensland fresh and marine waters (Veitch 1999). Max Winders & Associates (1998) observed no correlation with the use of GCTB in the catchments linked to fish kills. Direct fatalities from freshwater runoff and others indicating oxygen depletion from increased organic loadings were mentioned as possible causes. Many creeks at the time were showing signs of stress, with infestations of exotic water plants and low and variable DO levels.

In addition to the movement of organic matter to streams during run-off events, cane firing and harvesting operations have the potential to release labile carbon in the form of cane juice (mostly sucrose) to the environment. Juice is lost (up to 2.6% of total mass) through physical ejection and exudation from the heated stalk (Foster and Ivin 1981). Loss of cane juice as high as 30% is also known to occur during mechanical harvesting (Crook et al. 1999) of both burnt and unburnt cane, allowing transfer from plant to soil to water during wet weather harvest conditions and via irrigation water. This highly labile form of carbon (Queensland average of 0.26 tonnes of sucrose/ha/yr) has the potential to create a significant BOD, particularly when prolonged wet harvest conditions prevail (Rayment 1999), and when there is irrigation water runoff shortly after harvest.

Concentrations of DO can be lowered quickly due to chemical oxygen demand (COD) associated with reactions such as the oxidation of Fe2+ released in drainage from acid sulfate soils (ASS). For example, 20 mg/L of Fe2+ is equivalent to a COD of 1.4 mg/L of DO, assuming 50% oxidation to Fe3+ occurs. Flow weighted average concentrations of Fe2+ in drainage from an ASS site at Rocky Point, used for cane for over 30 years, have ranged from 12-33 mg Fe/L (Cook et al. 1999). The extended periods of low DO apparent in Figure 5-1 may be due to a combination of BOD and COD.

**Strongly acidic water**

Sulfuric acid is mobilised following the oxidation of pyritic minerals and jarosite in ASS. This strong acid and its reaction products, when allowed to drain to waterways, can result in serious acidification of streams and estuaries, adversely affecting ecosystem health (Sammut and Lines-Kelly 1996).

Water pH values of ≤ 3.5 have been linked to a range of undesirable impacts on waterplants, amphibians, biological processes and habitat value. At pH 3, common in estuarine waters affected by major discharges from ASS, the acid alone can cause necrosis and sloughing of epithelial cells (fish skin) and epithelial lifting. This damage increases as aluminium concentrations increase. Fish are also more susceptible to epizootic ulcerative syndrome (red-spot disease; associated with infection by Aphanomyces invadens) when epithelial cells are damaged by acid. However, the incidence of QX disease of oysters is independent of ASS conditions (Sammut et al. 1999).

Twenty-one percent of canelands in south-east Queensland (20,000 ha) are at potential risk
from ASS. Lesser areas are thought to exist in canelands of central and north Queensland but detailed ASS risk mapping has not occurred in those regions (Powell and Ahern 1999). In addition, 54% and 59% of NSW canelands have ASS positive horizons within 800 mm and between 800-1,500 mm of the surface, respectively (Rayment et al. 1999). It follows that strongly acidic waters can be an occasional water quality issue for considerable areas of canelands in eastern Australia.

**Benchmarks of surface water quality**

The first comprehensive collation of nutrient concentrations and fluxes in north Queensland coastal rivers and streams occurred in 1990 (Mitchell et al. 1991). Monitoring data (from 5 to 142 samples per stream) were from Birthday Creek to the O’Connell River. The main features were wide fluctuations in nutrient concentration, with suggestions of higher concentrations in wet seasons. Mitchell et al. (1991) noted that nitrate-N concentrations appeared to increase downstream in some rivers adjacent to sugarcane cultivation. In addition, there were suggestions that nutrient concentrations (particularly nitrate) increased in the first flushes after dry periods, an observation subsequently supported by Crossland et al. (1996).

Surface water quality data for 16 locations in the Johnstone Catchment were reported in late 1993 (Hunter 1993). Six of the sites were quantitative as they were supported by flow data and had sampling intensities up to 18 times per day during rare periods of moderate to high flows. In a period of low rainfall, up to 36% of dissolved N loads came from rainfall, suspended solids were predominantly low (<10 mg/L), reactive and total P at all but one site were < 0.05 and < 0.01 mg/L (good), while one or more forms of mineral or total N showed relatively high concentrations at half the sites on occasions. Concentrations of total N sometimes exceeded the 1992 ANZECC indicative upper concentration for ecosystem protection of 0.75 mg N/L.

In the lower Herbert Catchment, canelands were the greatest source of suspended solids in streamwater, with little sediment sourced from land supporting native and plantation forestry or cattle grazing. For the area studied, however, there was no clear evidence of an increase in sediment concentrations moving downstream as was the case for nutrients. In addition, concentrations of total soluble N and orthophosphate P in streams associated with sugarcane in the lower Herbert were generally greater than those associated with other land uses, and any differences between these were only seen during wet season peak flows. Also, nutrient (N and P) concentrations in the Herbert River at Ingham were greater than at Abergowrie, 32 km upstream, indicating an export of nutrients from land draining into the Herbert between these points (Bramley and Johnson 1996; Bramley and Roth 2001).

The Departments of Environment and Heritage and Natural Resources released in 1999 a 160-page publication “Testing the Waters” (DEH & DNR 1999). The publication contains spatially-referenced physicochemical and biological data on surface waters and physicochemical data on groundwaters. Parameters reported include DO, electrical conductivity (EC), turbidity, total P, oxidised N (nitrate), chlorophyll a, surface water macroinvertebrates, etc. Site condition for each of these parameters is typically colour coded, sometimes separately for riverine, estuarine and coastal conditions. Few “sugar” waterways were included in a separate grouping of rivers and estuaries with “high concentrations in selected parameters” (EC, turbidity, oxides of N, total P, chlorophyll a and DO), probably due in part to the relatively low numbers of sites in cane-growing areas and/or a general lack of “event-based” monitoring.

Finally, there have been two Queensland water quality summary reports in 2000 and 2001 with a focus on waterways in sugar-growing regions. The most recent of these (Wilhelm 2001) covers the five year period May 1995 through to April 2000 for 18 ambient water monitoring “stations” and up to eight parameters (pH, electrical conductivity, DO, turbidity, total N, ammonia, nitrate and total P). Turbidity levels commonly varied with time and stream, as did most other parameters. Refer to the widely circulated report for more details. It is hoped the reports such as these will enhance interest in using water quality as one benchmark of efforts to achieve sustainable
sugar production. Current CRC Sugar / SRDC interactive monitoring of six main drains in cane growing areas of NSW (Beattie, Green, Rayment) is also a move in the same direction.

Conclusions

The quality of water within, moving through, and discharged from canelands in eastern Australia has emerged across the last decade as an important environmental and emotional issue for the industry. Habitat loss and regular media attention on possible downstream impacts have influenced community perceptions. It is clear from this technical paper that much has been done to quantify “pressures” the sugar industry and at times other land and water users have or are having on nearby surface water quality.

The industry has lessened soil movement to waterways in recent years, much due to the wide adoption of GCTB in northern and central cane-growing regions of Queensland. However, the heavy use of fertilisers and to a lesser extent the recycling of mill muds on canelands exert on-going “pressure” on nutrient water quality for ecosystem protection, both on- and off-shore. As indicated for phosphorus by Bloesch et al. (1997), it will take many years for the benefits of lower or nil fertiliser inputs to be reflected in better water quality, due to the build in soil fertility that presently exists in most well established canegrowing areas.

While point source causes of low DO in sugar mill effluent have largely been resolved, diffuse causes appear to be increasing, based on recent monitoring in several areas. Growers in areas with ASS need to be vigilant to limit the liberation of Fe²⁺ to water, due to its significant COD. There is also a need for better guidance on acceptable organic matter loadings, including the significance of cane juice loss during mechanical harvesting. For example, New Zealand experience with lactose sugar in dairy effluent (Smith et al, 1993) suggests that BOD₃ values as low as < 5 mg/L can be responsible for downstream occurrences of sewage fungus growth. CRC Sugar research is current but until there is clarification of such issues, including the implementation of better cane harvester designs in the longer term, growers should apply the precautionary principle to their on-farm management practices that might adversely affect the DO status of surface waters in the vicinity of their farms. Preliminary guidelines are available (Hunt and Christiansen 2000; Rayment and Bohl 2002).

Benchmarking based on regular monitoring of surface quality has increased dramatically in the past decade but the spatial cover is very low. What is more, there has been little focus on event monitoring. Monitoring needs to increase so the industry can speak from a position of strength with respect to its actual and perceived impacts downstream. On the evidence emerging from the monitoring of main drains in northern NSW, the monitoring effort will need to be quite intensive in order to avoid the strong possibility of errors of extrapolation.

References


6. Nitrogen and groundwater quality

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Introduction

Off-site impacts due to nitrogen (N) and other nutrient/chemical losses from agricultural land use have come under increasing public scrutiny, particularly when they occur adjacent to sensitive wetlands, marine and estuarine systems, and world heritage areas such as tropical rainforests and the Great Barrier Reef. Because of the sugar industry’s location adjacent to many of these types of areas, it too is facing increasing scrutiny in terms of how it is dealing with these issues. Assuming an industry wide average fertiliser input of roughly 160 kg N/ha/yr, and an average output of roughly 80 kg N/ha/yr in millable cane, some 50% of the N applied in the industry can potentially be lost to the atmosphere and/or water systems (groundwater and/or surface water). Groundwater quality has thus become an important environmental issue for the sugar industry, especially given that in some areas (eg. Bundaberg) groundwaters also serve as an important source of drinking water.

When addressing these issues one also needs to be concerned about the contribution of nutrient losses via groundwater to total catchment nutrient export. The order of magnitude of N losses to groundwater (leaching losses) from sugarcane have been investigated on freely drained basaltic soils in the South Johnstone (Reghenzani et al. 1996; Hunter and Walton 1997) and under irrigated cane in the Bundaberg area (Kuhanesan et al. 1998; Verburg et al. 1998). However, no attempt has been made, apart from a recent modelling study (Thorburn et al. 1999), to quantify N-losses to groundwater for sugarcane on the soils on the alluvial plains in the wet tropics (Bristow et al. 1998). Consequently, CRC Sugar attempted to address this knowledge gap by studying N losses to groundwater using different methods and at different scales on typical floodplain soils in the lower Herbert. This work also addressed development of a robust methodological framework for recharge estimation to provide the industry with a tool to identify potential risk areas that might receive more targeted efforts in reducing nutrient leakage to groundwaters. The aim was to develop a modelling framework that could be applied at a subcatchment scale.

A new sampling procedure for groundwater nitrates

Groundwater sampling in the Herbert by CRC Sugar was carried out using a straddle packer device, which allows stratified groundwater sampling (Barber and Baxter 1983). For the purpose of determining N leaching losses, the N concentrations in the uppermost layer (0-100mm) of the aquifers were sampled. It is in this layer that the measured N concentrations most closely reflect the N load that has passed through the above soil profile because it is unaffected (diluted) by lateral fluxes and diffusion. Since groundwater movement is much slower compared to infiltration water/fronts moving through the profile, the very top of the aquifer works as a buffer integrating events and therefore requires a much lower time resolution in sampling compared to conventional suction cup measurements. (Noble, unpublished data)

A great proportion of the nitrate and related data obtained in earlier samplings (eg. Weier 1998) has been derived from samples that have been mixed over greater depths of the aquifer, producing average aquifer concentrations that may be far lower than the actual input at the surface of the aquifer. The data of Weier (1998)
are certainly useful for certain applications but could give misleading impressions of actual loading rates.

**Water and nitrogen balance (paddock scale)**

Recent research projects supported by the Sugar Research and Development Corporation (SRDC) and CRC Sugar have enabled construction of a complete water balance and large parts of the N balance for a typical floodplain soil under sugar cane in the lower Herbert (Table 6-1 and Table 6-2). This water/N balance constructed for a floodplain in the wet tropics is the first that has attempted to include interflow (the lateral flux from perched water tables to the drainage system and streams).

Interflow was calculated from measured perched water table heights using the approach by Youngs (1985), originally introduced for the design of land-drainage installations. The advantage of this approach is that it is physically based, which was the reason that it was recently applied to calculate drainage from acid sulfate soils (Cook et al. 1999). Recharge was determined from water table response and specific yield using the method of Prathapar and Sides (1993).

The water balance (Table 6-1) shows that recharge over the two years averaged ~430 mm/yr (~18% of rainfall), whereas an average of 230 mm/yr was drained via interflow (~10% of rain). Subsurface flow (recharge plus interflow) accounted for about 30% of the incident rainfall. Runoff was the major fate of incident rainfall with about 1000 mm/yr (~40% of rain). This was derived by difference.

N losses to groundwater/via interflow (kg N/ha/yr) were determined by combining the measured nitrate N concentrations in the groundwater/perched water with the calculated recharge/interflow values. Nitrate

<table>
<thead>
<tr>
<th>Year</th>
<th>Rainfall¹ (mm)</th>
<th>Evapotranspiration² (mm)</th>
<th>Recharge (mm)</th>
<th>Interflow (mm)</th>
<th>Runoff³ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>97/98 (%)</td>
<td>2596</td>
<td>756</td>
<td>332</td>
<td>213</td>
<td>1295</td>
</tr>
<tr>
<td>98/99 (%)</td>
<td>2153</td>
<td>683</td>
<td>530</td>
<td>241</td>
<td>699</td>
</tr>
<tr>
<td>Mean (%)</td>
<td>2375</td>
<td>720</td>
<td>431</td>
<td>227</td>
<td>997</td>
</tr>
</tbody>
</table>

¹ Rainfall measured on site  
² Evapotranspiration estimated with APSIM (G. Inman-Bamber, pers. com.)  
³ Runoff calculated by difference

**Table 6-2: Nitrogen balance numerically and as a percentage of total for a heavy textured floodplain soil in the Lower Herbert (Bohl et al. 2000) in 97/98 (plant cane) and 98/99 (1st ratoon)**

<table>
<thead>
<tr>
<th>Year</th>
<th>INPUT</th>
<th>OUTPUTS</th>
<th>Gaseous Losses/Runoff²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertiliser (kgN/ha)</td>
<td>Cane¹ (kgN/ha)</td>
<td>Recharge (kgN/ha)</td>
<td>Interflow (kgN/ha)</td>
</tr>
<tr>
<td>97/98 (%)</td>
<td>193</td>
<td>83</td>
<td>37</td>
</tr>
<tr>
<td>98/99 (%)</td>
<td>147</td>
<td>65</td>
<td>12</td>
</tr>
<tr>
<td>Mean (%)</td>
<td>170</td>
<td>74</td>
<td>25</td>
</tr>
</tbody>
</table>

¹ N-content of harvested cane determined / trash was considered to remain in the paddock  
² Gaseous losses and runoff calculated by difference
N concentrations were analysed using standard methods (Rayment and Higginson 1992).

Mean annual N loss via recharge was 15% (25 kg N/ha/yr), while N-losses via interflow accounted for 5% (8 kg N/ha/yr) of the applied N (Table 6-2). Therefore, subsurface flow (deep drainage and interflow) was not the major loss pathway for N in the lower Herbert. It seems more likely that gaseous losses (e.g., denitrification) or losses via surface runoff play the more important role, equivalent to about 40% of the applied N.

**Nitrate leaching losses (3 km transect)**

Nine bores were drilled in cane paddocks covering a representative transect over the three main geomorphological units of the Lower Herbert floodplain (Figure 6-1). The first unit, comprising the northern part of the study area (bores 1 and 2), consists of soils of the alluvial fans derived from granite and other acid volcanic rocks. The second unit contains the heavier textured (duplex) soils of low permeability of the alluvial plain, where waterlogging (generated by perched water tables) occurs regularly. This unit constitutes the larger and central part of the study area (bores 3, 4, 5, 6, 9 and 10). The third unit contains the sandy, freely drained soils of the river bank, bordering the Herbert River in the south of the study area (bore 7).

N leaching losses were calculated by multiplying recharge, determined with the method of Prathapar and Sides (1993), with nitrate N concentrations measured in the very top of the aquifer using the straddle packer device (see above).

Generally, there was great variation between the sites, and in some cases between the two years (Figure 6-1). The greatest losses occurred at bore 7 with 72 kg N/ha in 97/98, whereas the lowest losses occurred at bores 3 and 10 with 3 kg N/ha in 98/99. Most of the higher losses in 97/98 were under plant cane (bores 3, 10 and 7), which was expected due to the less developed root system. Bore 7 also showed relatively high losses in 98/99 (1st ratoon), which is probably due to the location of the bore on the more freely draining soils along the riverbank. The average N-loss to groundwater of all bores over the 2-year monitoring period was 17 kg N/ha/yr (Figure 6-1). Based on an average fertiliser input of 160 kg N/ha/yr (BSES recommendation), the amount leached to the groundwater was equivalent to about 10% of that applied. The average N loss to groundwater was 24 kg N/ha for the year 97/98 and 9 kg N/ha for the year 98/99, which was equivalent to 15 and 5% of fertiliser input, respectively.

**Nitrate leaching losses (262 ha area)**

Streamflow measurements were carried out in the major drain in the area (draining 262 ha of cane land) for two years. With these data a rainfall-runoff model (IHACRES) was calibrated and the baseflow component derived, which accounts for the groundwater/interflow contribution (Figure 6-2). The combination of retrospectively modelled baseflows for the years 1992 to 1995 with N concentrations measured during slow flow within the CSIRO’s Coastal Zone Program (Bramley and Muller 1999) in the same period allowed the calculation of N losses via subsurface flow.

The average N loss over 3 years was 21 kg N/ha/yr. The lower losses occurred in the drier seasons 92/93 and 94/95 (18 and 13 kg
Spatial variation in nitrate leaching (100 km² sub-catchment)

The need for a robust methodological framework for recharge estimation has existed for many years, and was attempted as part of this CRC Sugar supported research. It is based primarily on making better use of existing data (soil resource information, climate data) and available tools (water balance models, GIS), and involves grouping mapped soil types (pedological units) into similar functional hydrological units based on hydrological criteria (Timmer 1998). Recharge estimates for each pedohydrological unit are then obtained through water balance modelling of representative soil types within a particular unit (Tetzlaff 1998). Once the hydraulic properties for a pedohydrological unit have been quantified, one just needs climate input data to allow extrapolation to other areas. The advantage is that with current access to reasonable quality climate data, only representative soil physical data have to be measured, or estimated with the help of pedotransfer functions (Bristow et al. 1999).

This approach has been applied in the Ripple Creek area of the lower Herbert catchment with encouraging results (see Map 1).

The recharge estimates (Map 1) were then combined with the average yearly nitrate concentrations measured with the new sampling technique in the upper aquifers of the area. The calculated N-losses (see Map 2) are in

---

**Table 6-3:** Comparison of nitrogen losses to groundwater at different scales (paddock and transect losses derived from concentrations in bores, area losses from baseflow concentrations)

<table>
<thead>
<tr>
<th></th>
<th>Year</th>
<th>Rainfall (mm)</th>
<th>Recharge/Baseflow (% of rain)</th>
<th>N loss (kgN/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paddock</td>
<td>97/98</td>
<td>2596</td>
<td>13</td>
<td>37</td>
</tr>
<tr>
<td>(1 ha)</td>
<td>98/99</td>
<td>2153</td>
<td>25</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>2375</td>
<td>19</td>
<td>25</td>
</tr>
<tr>
<td>Transect</td>
<td>97/98</td>
<td>2596</td>
<td>16</td>
<td>24</td>
</tr>
<tr>
<td>(3 km)</td>
<td>98/99</td>
<td>2153</td>
<td>20</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>2375</td>
<td>18</td>
<td>17</td>
</tr>
<tr>
<td>Area</td>
<td>92/93</td>
<td>1456</td>
<td>14</td>
<td>18</td>
</tr>
<tr>
<td>(262 ha)</td>
<td>93/94</td>
<td>2060</td>
<td>33</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>94/95</td>
<td>1316</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>1611</td>
<td>20</td>
<td>21</td>
</tr>
</tbody>
</table>

**Figure 6-2:** Calibration of the rainfall runoff model (IHACRES) and baseflow separation as the basis for calculating N losses via subsurface flow (groundwater and interflow) for a cane area of 262 ha in the Ripple Creek subcatchment, Lower Herbert
the range 0-15 kg N/ha/yr. These losses are in general lower than the losses described earlier (Table 6-3), probably due to the recharge modelling which was carried out over 7 mostly dry years. Nevertheless, the potential risk areas for leaching losses (colluvial fans and river bank soils) could be easily identified. Furthermore, qualitative information about the probability of N-losses via runoff can be indirectly deduced (low recharge = high probability of runoff).
Conclusions

A complete water balance including interflow, and large parts of the N balance have been constructed for a floodplain soil under sugar cane in the wet tropics (paddock scale). Based on a new groundwater sampling procedure, introduced for determining N leachate concentrations, the N-losses to groundwater from cane land over the main geomorphological units of the Lower Herbert floodplain were quantified (transect 3 km) and verified from baseflow N concentrations (area 262 ha). Average N losses to/via groundwater determined by these different methods and at different scales were about 20 kg N/ha/yr, which is equivalent to 10 to 15% of the N fertiliser applied. However, larger losses (up to 70 kg N/ha/yr) occurred under plant cane on a freely draining soil on the riverbank. These results suggest that subsurface flow (groundwater and interflow) is not the major N loss pathway for these particular wet tropics floodplain soils. Future research should aim to include quantification of gaseous losses and losses via surface runoff to gain more confidence about the main N loss pathways. In particular, denitrification could play a major role under these moist and/or waterlogged conditions.

Progress has also been made towards providing the sugar industry with a more robust modelling framework (pedohydrological unit approach) to help identify potential high risk areas. This tool, based primarily on existing data, can be used to estimate recharge, which when combined with the new groundwater sampling procedure, can yield estimates of the spatial distribution of N-losses at large scales. The approach, demonstrated at a sub catchment scale (~100 km²), has potential to assist with a range of issues from more efficient nutrient management and targeting of future R&D investments, through to allocation of cane land.

References


7. Pesticides and water quality

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\section*{Introduction}

Pesticide usage by the Australian sugar industry provides an effective and efficient management input for maximising productivity. As with fertiliser usage, cane growers are provided with a range of options on the type of product, application techniques, timing, and other related variables. Historically, selection of such options focussed primarily on the key issues of cost and efficacy. Whilst these continue to be the main drivers, there is now increasing consideration of potential environmental impacts. It is now well accepted that the on-going registration of pesticides is closely linked to their environmental fate and impacts.

Pesticides include the herbicides, fungicides, insecticides and other major classes of pest control compounds. Application of pesticides in cane production is normally focussed on the period from planting or harvesting to when the canopy is well developed. The bulk of this application normally falls before the on-set of summer rains. Herbicides, used for weed control, are surface applied using a range of spray application techniques whereas the major insecticide usage (chlorpyrifos) is via controlled release formulations applied sub-surface at planting.

To help cane growers make informed decisions on the environmental aspects of pesticide behaviour, there is need to have access to information, which is based on sound scientific studies. Without such information, growers are left to the uncertainties of conflicting reports and can be targeted by those who simply oppose chemical use, inferring that all chemicals are damaging to the environment. It is also increasingly critical, that any current practices, which are environmentally threatening, are rapidly identified and the information made available to growers so that such practices cease or are modified.

Fortunately, the scientific literature contains excellent data on the physical and chemical properties of many pesticides, including some well-documented studies on the environmental fate and persistence of some of the most widely used compounds. Such reports provide a useful guide but because many studies are conducted in temperate environments, they may be totally misleading for Australia’s tropical and sub-tropical conditions. It is clear that the Australian cane growing industry needs reliable local data that is directly applicable to our conditions so that there is confidence and credibility in the information underpinning any changed management strategies.

The challenge for pesticide scientists and for research funding bodies is to undertake specific studies, which help to provide key data for the specific study sites, but which can also be used beyond the immediate study area i.e. extrapolated to a wider cane growing community. A solution is to undertake studies, which aim at improving our understanding of the underlying processes. With a good understanding of the processes, there is a chance of effective extrapolation to other areas, other conditions and other pesticides (existing or future). There is also a need to integrate the pesticide work with related activities, such as those involving analysis of irrigation and water movement through sugarcane catchments.

To help in the process, the CRC for Sustainable Sugar Production has enabled integration of information from projects on pesticide studies, ranging from the Atherton Tableland (ACIAR, DNR), South Johnstone (ACIAR, DNR),
Herbert/Burdekin (CRC/AIMS), Burdekin (CRC, SRDC, BSES), Bundaberg/Childers (CRC, DNR, BSES, SRDC, ACIAR) and Northern N.S.W. (CRC, BSES, SRDC, and NSW Sugar Milling Co-operative Ltd). In this section we highlight some of the key features resulting from this work.

**Pesticide fundamentals**

**Inputs**

A prerequisite for designing and prioritising research or monitoring programs is to have sound information on the pesticide usage (inputs). Such information is also essential for effective interpretation of monitoring data.

Studies by Hamilton and Haydon (1996,1997) obtained estimates of annual pesticide usage (kg of active ingredient) at catchment and mill-area scale for both the Queensland and New South Wales sugar growing areas. The herbicides atrazine and diuron were shown to be the most used with annual inputs of over 365,000 kg and 203,000 kg, respectively (Table 7-1).

The relative mobility of some of these compounds, particularly atrazine, has raised community and regulatory concerns, regarding the off-site movement to both surface and groundwaters. Other compounds such as chlorpyrifos, paraquat or the previously used persistent organochlorines, are more firmly bound to sediment and thus are generally not an issue for groundwater contamination but can move to surface waters in runoff.

Studies by Ham (1994-1998) in the Burdekin showed that diuron was the most frequently detected herbicide in irrigation tailwater with a maximum concentration of 62 µg/L, but generally in the range of 3-25 µg/L. Atrazine and 2,4-D were also detected at 68-70 µg/L and 11-12 µg/L respectively over a three-day period at one site. Chlorpyrifos, generally applied at planting as a controlled release formulation was not detected in runoff (0.2µg/L detection limit).

Related studies by Simpson *et al* (1997-2000) in the Cattle Creek catchment of the Atherton Tableland (ACIAR/DNR), have shown concentrations of atrazine and diuron in Cattle Creek reaching a maximum concentration of approximately 25 (g/L and 20 µg/L respectively prior to the wet season ie., during the spring-summer pesticide application period. Whilst the total quantities of atrazine and diuron exported over both the 1997/98 and 1998/99 seasons were in the range of only 1-2% of the quantity applied (Figure 7-1), concentrations were higher than desirable for defined periods.

Preliminary data from the New South Wales study (Beattie *et al*, 1999) on the pesticide and nutrient levels in farm drains show that herbicide concentrations are appearing at concentrations that will require some attention. Whilst most studies focus on contemporary pesticides, the study by Cavanagh (1999) demonstrated that the previously used

**Table 7-1: Estimates of annual major pesticide usage (Eastern Australian sugar production)**

<table>
<thead>
<tr>
<th>Pesticide</th>
<th>Queensland*</th>
<th>New South Wales*</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atrazine</td>
<td>331 000</td>
<td>34 800</td>
<td>365 800</td>
</tr>
<tr>
<td>Diuron</td>
<td>197 000</td>
<td>6 600</td>
<td>203 600</td>
</tr>
<tr>
<td>2,4-D</td>
<td>141 000</td>
<td>11 200</td>
<td>152 200</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>85 600</td>
<td>13 100</td>
<td>98 700</td>
</tr>
<tr>
<td>Ametyn</td>
<td>76 000</td>
<td>1 200</td>
<td>77 200</td>
</tr>
<tr>
<td>Chlorpyrifos</td>
<td>74 500</td>
<td>5 100</td>
<td>79 600</td>
</tr>
<tr>
<td>Paraquat</td>
<td>42 800</td>
<td>6 500</td>
<td>49 300</td>
</tr>
<tr>
<td>Trifluralin</td>
<td>21 200</td>
<td>420</td>
<td>21 620</td>
</tr>
</tbody>
</table>

*Areas of sugarcane production in Queensland and New South Wales were 416,000 ha and 34,000 ha, respectively.*

(kg of active ingredient) at catchment and mill-area scale for both the Queensland and New South Wales sugar growing areas. The herbicides atrazine and diuron were shown to be the most used with annual inputs of over 365,000 kg and 203,000 kg, respectively (Table 7-1).
persistent organochlorines, namely BHC, chlordane, DDT, dieldrin, and heptachlor are still resident in some cane soils and are moving off-site in the sediment phase, with the potential to be exported large distances. Cavanagh’s work has also shown elevated levels of ethoxyresorufin O-deethylase (EROD) activity in fish (signal of exposure to organic contaminants) are occurring in streams in agricultural catchments in tropical Queensland.

Current Australian (ANZECC) water quality guideline values for pesticides in environmental waters are limited. However it is clear that concentrations of pesticides leaving the end of a furrow in irrigation tailwater (or from rainfall runoff) can be well above guideline values for natural streams or waterways. The current draft ANZECC guideline value for atrazine is 0.5 µg/L. The data obtained by Ham and Simpson et al highlights the need to manage tailwater and runoff so that concentrations entering waterways are minimised.

Risk Periods

The potential for pesticide moving off-site is governed by a number of key parameters including climatic, topographic and hydrologic characteristics of the area. The risk of significant concentrations leaving the system is clearly linked to the amount of pesticide present at the time of a significant rainfall or irrigation event. Management of such risk must therefore be based on a sound knowledge of the persistence of the pesticide in the farming system, particularly the concentrations of pesticide remaining in the top layer (0-2.5 cm) of soil.

Soil Concentrations

CRC Sugar studies by Simpson et al (1997-2000) have provided the first Australian data on the dissipation of a number of widely used pesticides under sugar production. Conducted on a number of sites in the Bundaberg/Childers area, these data are being used to help define the key risk periods for pesticide movement.

Figure 7-2 shows the dissipation of a range of pesticides in the 0-2.5 cm layer of a redoxic hydrosol soil during the period September 1997 to January 2000. Rainfall during this period was extremely varied with the 1997/98 season being well below average rainfall over the initial dissipation period but more normal rainfall in the latter part of the study. Where rainfall occurred in the period shortly after application, dissipation rates (DT₅₀) were reduced to days. The term “dissipation time (DT₅₀)” or “dissipation rate (DT₅₀)” is used to describe the time taken for the applied compound to reduce to 50% of the starting concentration. It is commonly used for field studies where multiple processes (chemical/physical/biological) are involved. The term half-life...
(t_{1/2}) is often used but this is better suited to controlled conditions and infers first order decay. Dissipation rate (DT_{50}) makes no assumption on the kinetics.

These data show that major risk periods (Figure 7-2 — shaded areas) are confined to the periods immediately after application and thus management strategies for minimising off-site movement must address this period but are not as crucial at other times. The data also suggests that there is no evidence of pesticide “build-up” from repeated applications on this redoxic hydrosol.

Whilst similar results were obtained on grey kandosol and yellow chromosol soils under similar conditions of rainfall and temperature, there is evidence that build-up of diuron is occurring from annual application of diuron at normal recommended rates on a red ferrosol (oxisol). Figure 7-3 shows that following an initial period where diuron levels reduce as expected, diuron then remains almost constant until the next application the following season. This is in contrast to the behaviour of the other pesticides studied on this site.

Table 7-2 shows that apart from diuron on the red ferrosol, dissipation rates (DT_{50}) of pesticides on the four soils were relatively fast, but variable depending on rainfall conditions, eg. 1-28 days in the 0-2.5 cm and 3.5-23 days in the 0-50 cm layer for atrazine.

Whilst soil profile sampling at all sites showed some downward movement of pesticides in the soil matrix (Figure 7-4), there was no evidence of significant leaching under the conditions studied.

Impact on Water Quality

From the data obtained, it would seem that most of the pesticide dissipation on these sites

<table>
<thead>
<tr>
<th>Season</th>
<th>Spring 97</th>
<th>Summer 97/98</th>
<th>Summer 98/99</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Atrazine</td>
<td>Trifluralin</td>
<td>Atrazine</td>
</tr>
<tr>
<td>Site 1: yellow chromosol</td>
<td>0-2.5 cm</td>
<td>0-5 cm</td>
<td>10-50 cm</td>
</tr>
<tr>
<td>Site 2: grey kandosol</td>
<td>0-2.5 cm</td>
<td>0-5 cm</td>
<td>0-50 cm</td>
</tr>
<tr>
<td>Site 3: red ferrosol</td>
<td>0-2.5 cm</td>
<td>0-5 cm</td>
<td>0-50 cm</td>
</tr>
<tr>
<td>Site 4: redoxic hydrosol</td>
<td>0-2.5 cm</td>
<td>0-5 cm</td>
<td>0-50 cm</td>
</tr>
</tbody>
</table>

* sampling terminated after 250 days # sampling terminated after 150 days

Figure 7-3: Dissipation of pesticides from soil surface (0-2.5 cm) — red ferrosol

Table 7-2: Dissipation times (DT_{50}) for herbicides (days)
is a result of chemical and biological processes on site, rather than a result of runoff or leaching. Losses due to runoff will range from zero to perhaps 2-3% of the amount applied, depending on the rainfall or irrigation after application. On sandy or other well-drained soils, particularly under high rainfall conditions, losses due to leaching could be high.

Despite the fact that the percentage of off-site movement may be low, concentrations in runoff or leachate can be high. The significance of such concentrations must take account of the distance and processes between the point of discharge and the receiving waters and the relative volumes of the discharge and receiving waters. Whilst there are number of strategies available for “diluting” the concentrations in runoff before it reaches sensitive areas (if conditions allow), strategies for reducing pesticide concentrations leaving the cane rows must be based on a good knowledge of the composition of runoff (pesticide and sediment concentrations), as well as detailed knowledge of the risk periods.

As an example of the processes being studied, a runoff event (from a redoxic hydrosol site) resulting from a 40.5 mm rainfall over 2.5 hours in October 1999 (seven days after pesticide application) produced approximately 35% of the rainfall as runoff. Atrazine concentrations averaged 144µg/L, 288 times the draft ANZECC guideline values of 0.5µg/L for environmental waters and chlorpyrifos averaged 21µg/L, 21,000 times the draft ANZECC guideline value of 0.001µg/L. It must be stressed that chlorpyrifos was applied as a surface application at recommended rates for army worm control (not as the controlled release formulation eg. SusCon Blue). It also must be stressed that these concentrations refer to the runoff leaving the end of the furrow, not levels measured in a stream or other natural waterway.

Based on the pesticide concentrations present in the soil immediately prior to the runoff event, predictions of concentrations in runoff, had the event occurred in the hours immediately after application, would be 720 µg/L for atrazine and 61 µg/L for chlorpyrifos (1440 and 61,000 times the draft ANZECC guideline values respectively). Had the event occurred 14 days after application (one week after the actual runoff event), predicted concentrations in the runoff would have dropped to 20 µg/L (atrazine) and 11µg/L (chlorpyrifos), 40 and 11,000 times the ANZECC guideline values, respectively.

Initial data suggests that atrazine levels in shallow groundwater collected immediately after the event (from a piezometer) exceeded 300 µg/L.

In the previous season, storm runoff from a grey kandsol site, one day after application of atrazine and ametryn produced concentrations of 180 µg/L and 140 µg/L, respectively.

The importance of this information is to quantify and to define the processes producing source contaminant. How this would impact on receiving waters will vary considerably. As such, it is necessary to consider the discharge (runoff) points for the farm and the distance, slope and surface condition (eg. vegetation) in the catchment leading to the receiving waters. The vulnerability of natural ecosystems will therefore be highly varied and great care should be given to seriously considering such variation. High concentrations of pesticides leaving the end of a furrow in storm runoff or tailwater may have either minimal effect on

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**Figure 7-4: Measurement of diuron and atrazine movement in soil profile (grey kandsol)**
downstream water quality or in another situation, could be the cause of environmental damage to the local ecosystem (aquatic flora and fauna).

Current available data on the pesticide levels in coastal streams, waterways or groundwater is limited. Monitoring is expensive and thus tends to be limited in both frequency and numbers. Such limited data and the resultant limited cases of documented excessive residues may provide a false confidence that few problems exist. However, the limited data that are available clearly show that relatively high concentrations of pesticides can be deposited in rivers, dams or lagoons and the more mobile herbicides such as atrazine are moving into shallow groundwater in some areas. To date, no significant levels of the common metabolites of atrazine were measured in the soil profile. However, the presence of desethylatrazine was detected in both surface runoff and in subsurface water.

Initial comparison of the relative adsorption properties (Kd) of a number of sugarcane pesticides on a range of surface and subsurface soils studied in the CRC Sugar and related ACIAR funded studies, shows significant variation across pesticides, soil type and soil depth. In general these data also show that for most soils, the pesticide adsorption decreases with depth. This highlights the need to keep pesticides in the upper layer for as long as possible (e.g. avoid excessive rainfall/irrigation after spraying and maintain organic matter) and to be aware that re-shaping/levelling the land may significantly change the pesticide adsorption characteristics on the surface (and sub-surface).

Conclusions

The data obtained to date clearly indicate that higher than desirable levels of pesticides can reach natural waterways. It is also clear that if care is not taken to avoid high-risk conditions (high soil residues combined with significant runoff or leaching), that environmental guideline values will be exceeded, resulting in the potential for environmental harm or regulatory action. To date, the findings have been progressively made available at grower meetings, workshops, conferences and at the CRC Sugar Short Courses. Further work is needed to extend this process.

Defining the risk periods will help to define the most vulnerable time for off-site movement and, combined with increased understanding of the off-site processes, will help to develop effective management strategies. The clear suggestion that the herbicide diuron is unusually persistent in at least one of the soils studied (red ferrosol), warrants serious follow up to identify other potential conditions where annual applications of diuron may lead to unacceptable build-up of residues in the soil, thus increasing the risk of off-site movement via water and sediment runoff.

To extrapolate current findings to other areas with different soil types, topographic and hydrologic conditions, there is an ongoing need to obtain the information on the differences in pesticide behaviour on different soils eg. dissipation rates DT50 or half life (t1/2), and the soil/water partition coefficients (Kd). Fortunately much of this can be determined in the laboratory, without expensive field experiments. With sufficient parameters available, modelling will help to predict and quantify the impact of changes in management practices and conditions.

Because of the greater use and acceptance of visualisation products, such strategies should be encouraged as a framework for communicating the risk areas and risk conditions for certain pesticide use and thus strongly position the industry with credible decision support tools for addressing management needs. The potential for off-site contamination can be effectively reduced if such new information is effectively communicated to the industry leaders and to growers. Continued promotion of best management practices for pesticide use is an essential element for maintaining a sustainable environment and industry.
References


Ham, G. 1994-1998. BSS122 Nutrients and pesticides in surface drainage water and soil under irrigated sugarcane - BSES, SRDC and CRC Sugar. (Final Report)


Introduction

As inhabitants of the driest continent, Australians have always been heavily reliant on water supplies which are variable in quantity and quality. Water is valued for drinking, irrigation, industrial and urban uses, recreation and to support fisheries habitats. Sufficient water supply was traditionally the major issue influencing agricultural development and productivity.

Water supply, quality and management have been the focus of major debate throughout Australia in recent years. Environmental flows, induced salinity, algal blooms and water quality have been contentious issues in many areas of the nation. The irrigation section of this document has outlined some of the supply issues and other threats to resources posed by water management.

The response by government and industry to water supply issues has taken two main approaches:

- The development of improved irrigation practices to achieve optimum economic benefit from limited water supplies and minimise potentially deleterious impacts of excess water use; and
- Modifying water allocation procedures to ensure fair distribution of resources amongst all water users, including the environment.

Many aspects of farm management may impact on community and/or environmental values for water. Both irrigation and drainage have significant impacts on flow regimes. Runoff water and deep drainage may also carry sediments and agricultural inputs such as fertilisers and chemicals. The management of native vegetation, in particular riparian lands and wetlands will also impact on water quality, flow and the habitat value of waterways.

Drainage, crucial to improving productivity in many areas, may impact on natural resources by:

- Altering regional hydrology;
- Lowering natural water table levels;
- Transporting sediments, nutrients and other agricultural inputs from the farm;
- Disturbing acid sulfate soils;
- Loss of wetlands, either directly or as an indirect result of the hydrological changes;
- Reducing the period of time that water is retained in catchment areas, thereby reducing recharge to aquifers and the settling of nutrients and sediments from water and increased incidents of flooding downstream;
- Providing additional fisheries habitat in well maintained drains;
- Improving productivity.

Potential adverse and beneficial impacts of irrigation include:

- Enhanced productivity;
- Improved management opportunities to incorporate fertilisers, etc.
- Alterations to stream flow — both quantity and frequency of flow due to water
extraction and irrigation infrastructure;
- Fewer incidences of flooding downstream where dams are in place;
- Transport of solutes in tail water;
- Induced salinity;
- Competition for water resources.

As a result of community concerns, industries are expected to adopt practices that will reduce adverse impacts on the broader environment. This is particularly the case with water quality. Expansion of the sugar industry has placed increased pressure on water resources.

**Identifying Research and Extension Priorities**

Community concerns about water management are widely expressed, often based on anecdotal associations, and at times emotionally, through the media. In working to address these concerns, it is important to have a good understanding of the views of a broad cross-section of the community.

CRC Sugar’s Program Consultative Groups have been established for each of the programs and cross-programs. These groups comprise representatives of industry, community and government stakeholders. They meet regularly, generally twice annually, to provide input to and comment on the activities of their respective programs. In addition to this, stakeholder consultations have been undertaken by CRC Sugar to identify values and plan future research activities. Water issues are included, either directly or indirectly in these reviews.

**CRC Sugar Strategic Planning**

A stakeholder consultation, to identify key needs and issues, was undertaken in 1998 for CRC Sugar’s strategic planning process by the ORION Consulting group. This report has compiled the key issues and concerns raised by community, industry, government and research groups in relation to the role of CRC Sugar. Water related issues raised in these discussions included both the impacts on water quality and the need for water for irrigation. The relative importance of each varied between districts.

Environmental issues dominated all of the NSW interviews. In NSW, the growers, millers, the Government and research groups identified water quality issues, in particular acid sulfate soils (ASS), as the major issues for the industry in that area. The positive outcomes of the ASS project were mentioned several times. The government representatives indicated that they considered the sugar industry to have a good handle on ASS management and that they preferred industry self-regulation to local government enforcement. The industry expressed a desire to take a similar, proactive approach to water quality management and monitoring, requesting CRC Sugar assistance to establish a monitoring regime to measure nutrient and pesticide run-off. An activity is now underway to address this need.

In Bundaberg, the availability of water for irrigation was a key priority. This was perhaps exaggerated by the extremely dry conditions and controversy over a new dam proposal. The construction of additional water infrastructure, on-farm water storages and improved water use efficiency were seen by growers, millers and agribusiness as the key requirements for the sugar industry in this area. Management of groundwater, in particular salt-water intrusion, was a high priority. The environmental group in the area expressed concerns about the approach of the industry to achieve water supplies ‘at any cost’. These representatives considered that the industry ‘lacked balance’ between production and the environment.

Water supply issues were also identified in Mackay by both industry and environmental groups. Again, a proposed new dam was high on the local agenda at the time and may have led to the debate over this issue. On-farm storages were considered by environmental representatives in Mackay to be less intrusive on the environment. Environmental representatives were also concerned about water use and proposed dams on the Tablelands.

Other issues related to water identified by environmental representatives throughout Queensland included:
- need for monitoring of water quality;
- need for more research into the downstream
impacts of water quality, particularly the impacts on fish life; (this was also identified by the research/government groups)

- the condition of waterways in cane growing areas — the need for management of waterways and riparian zones and restrictions on expansion into riparian areas;
- concerns over the expansion into more marginal lands;
- higher herbicide usage - what are the impacts?
- movement of mercury in water and sediment;
- need for legislation to be enforced, eg as it applies to watercourse protection;
- cost sharing between landholders and community in the rehabilitation of degraded land and rivers.

Agribusiness groups identified green cane trash blanketing as a major improvement in reducing runoff and improving irrigation efficiency. However, drainage design and the loss of wetlands were considered to cause greater sediment movement into river plumes. Riparian zone management was seen to be inappropriate in some areas, particularly the loss of continuity in effective riparian vegetation along creeks. Tighter controls on expansion were considered necessary with action needing to be taken where guidelines have been breached. These groups were quite varied in their responses in different regions. Some called for greater use of soil testing and monitoring of runoff and uptake of fertiliser. Education about correct storage and disposal of chemicals and chemical containers was considered important. The importance of healthy waterways to support fish life was raised repeatedly.

Many agribusiness and government/research representatives, and some environment representatives identified cane growing as a major contributor to the local economy in their regions. A few different groups expressed concern about the disposal of mill waste water into waterways, particularly at high temperatures.

While water supply issues dominated discussions with growers and millers in Bundaberg, the issues raised in this region on other topics were highly varied. Public pressure and possible trade barriers related to environmental management were raised, along with the need for research to keep the industry competitive on the world market. Specific areas included productivity enhancement and cost reductions, disease and pest management, dirt and extraneous matter, sugar quality, soil health and industry PR. Other than in NSW, water quality issues did not dominate discussions with the growing and milling sector. The need for greater water use efficiency was raised again, with one view expressed that restricted water availability may be the key trigger to force change in grower’s irrigation practices. There were often opinions expressed that environmental research should be used to refute claims by environmental lobby groups.

Government and research groups also raised varied issues in different districts and varied in their apparent knowledge of the industry. The need for expansion controls was commonly expressed. Also expressed was the need to merge the ‘productivity’ and ‘environment’ camps of CRC Sugar. It was suggested that CRC Sugar take control of the environment agenda to facilitate more informed debate. The impact of agricultural production on downstream ecology was considered a gap that needed further research. The need for water quality monitoring and coordination of existing monitoring programs was again expressed. Educating local government (shires and councils) about industry practices and research activities was considered important.

**Extension Priorities**

In developing an extension strategy for CRC Sugar, it is important to understand the concerns and opinions of other stakeholders. For this reason, CRC Sugar’s Environmental Technology Transfer Officer consulted with a range of industry and community stakeholders throughout Queensland and News South Wales coastal areas to identify extension requirements (Hunt, 1999).

Semi-structured interviews were conducted with representatives of stakeholder groups in order to identify significant issues and determine how the extension and communication programs of CRC Sugar may assist the industry address these issues. These
interviews were conducted with a sample of sugar industry advisors, State Government Department advisors and community group representatives from all sugar cane growing regions in Queensland and New South Wales. Community group representatives were from organisations such as conservation groups and recreational fishing organisations. The study also drew on discussions with the broader community. In total, 42 people were interviewed.

These interviews and discussions focussed on:
(a) Environmental / sustainability issues relevant to the sugar industry, with which members of the community are concerned;
(b) Specific local on-farm activities, which have perceived environmental implications;
(c) Current level of interaction between the industry and other stakeholder groups.

The purpose of the study was to develop a greater understanding of regional stakeholder concerns relating to the sugar industry’s environmental performance. This information is being used to provide direction for future extension and communication activities.

The issues raised in relation to water management are discussed below. The findings highlight issues of apparent concern to stakeholders, which may require further research, extension and/or communication between the sugar industry and stakeholders.

**Water quality**

Water quality issues were recognised as very important across the range of respondents and regions. Water quality was found to be the most commonly discussed issue with 60% of industry respondents and 100% of departmental advisors and community representatives contributing comments. Whilst it was discussed by participants in all regions, industry comments about the issue came mainly from advisors in the Far North, Herbert, Burdekin, Mackay and NSW regions. This is likely to be the result of past (and sometimes very recent) community interest in water quality in these areas relating to fish kills, tail water management, and acid sulfate soil drainage.

Industry stakeholders’ comments tend to focus on the lack of a clear scientific message on downstream impacts of agricultural land use, and lack of consistent departmental policies on such issues. 50% of those advisors (industry and departmental) who were interviewed identified that further investigation of water quality issues and examination of the benefits of alternative agricultural practices was warranted. This apparent lack of a clear answer to water quality issues is an indication of the complexity of the issue.

Industry extension advisors offered a range of suggestions to address issues including: alternative fertilisers; closer monitoring of nutrient inputs, reduction in stockpiling of mill mud; amending mill mud and/or dunder application procedures; generating a positive focus on dunder and mill mud; laser levelling to reduce soil nutrient losses. Industry advisors expressed considerable interest in the management of sediment and nutrient losses.

Participative water quality projects in NSW have been recognised by extension advisors and researchers for their effectiveness in raising stakeholder understanding and improving on-ground implementation of best practices and technologies. Similar programs have potential application in other districts, particularly the Wet Tropics, Herbert, and Mackay where community concern regarding water quality has been strongest.

As expected, community group and departmental representatives provided comments on the potential impact on waterways of elevated nutrients and sediment loads. 33% made specific reference to possible nutrient links to fish kills and weed problems in waterways. Improvements in distribution of milling by-products, such as dunder and mill mud, were supported by at least one community representative, who recognised the need to continue recycling of by-products on cane farms. One community representative considered irrigation of sugarcane to be a potential solution to effluent disposal concerns in the Tinaroo Dam catchment.

**Riparian buffers, wetlands and habitats**

The issues of riparian zones, wetlands and habitats are closely linked with water quality.
They were widely identified by respondents in the Far North (60%), Burdekin (50%), and Mackay (40%), and to a lesser degree in Bundaberg and Southern Queensland. Departmental advisors and community representatives were responsible for most of these responses. Three advisors and four community representatives said that this was one of the most significant issues.

Significantly there is less emphasis on riparian, wetland and habitat issues in southern districts and NSW, although it was discussed by one community group representative as an issue in expansion areas of southern Queensland. Reasons for this lack of response are not clear, but could relate to a lack of acute water quality issues in these regions.

Most community participants quoted the values of riparian vegetation. There appears to be a good understanding of the role of riparian vegetation amongst community stakeholder groups. Two community representatives (Mackay and Far North) considered riparian revegetation to be a very important component of water quality solutions. State of the River’s reports (Anderson, 1993; Moller, 1996) from two cane growing catchments have highlighted the generally poor quality and quantity of remaining riparian systems.

The development of more economical and effective revegetation techniques is seen as an area requiring additional research. These should also address the issues of cost sharing between industry and community raised by Chudleigh, Bramwell and McLeod (1997).

The need for a community based rate relief scheme or other incentive packages to remove the economic burden from affected landholders has long been identified by both community and industry bodies. Some local authorities have introduced rate relief schemes to encourage and assist landholders to rehabilitate such areas on private property. Two large revegetation programs, funded primarily through the Natural Heritage Trust, exist in the Wet Tropics (Wet Tropics Tree Planting Scheme) and Mackay/Whitsunday (Central Coast Revegetation Initiative) to undertake high priority restoration works, including riparian revegetation.

Very strong opinions were expressed by a community representative in north Queensland that many of the issues of ASS, drainage and pollution stem largely from the past development of wetlands. A departmental advisor supported this concern, suggesting that much of the area suffering from water logging in Far North Queensland is land that was formerly wetland. These parties also regarded the impacts of receiving drainage waters on wetlands as an issue, particularly the quality of irrigation tail water entering natural wetlands.

Quote: “If wetlands were maintained they would help absorb runoff, chemicals, etc resulting in reduced impacts on other critical fishery areas (estuaries). However their filtering/ buffering capacity should not be exploited to the wetland’s ecological detriment.”

Protection of the ecological values of remaining wetlands and the functions of riparian vegetation was high on the agenda for community groups and conservation agencies. Construction of water storages on existing wetland sites in the Mackay district was seen as inappropriate by one community group respondent. Also of concern is the loss of threatened habitats in heavily developed coastal areas. Community and departmental respondents in southern Queensland expressed concern about the loss of *Melaleuca* wetlands in the region. The concerns focussed particularly on the likelihood that the filtering role provided by *Melaleuca* wetlands are being lost from the landscape at the same time that land development is increasing pollutant loads in water.

As development and expansion continues, these issues will become more significant for the sugar industry and other land uses. Involvement of Sugar Industry Liaison Officers (Queensland Environmental Protection Agency) and local conservation organisations in land use planning activities should be encouraged in all districts to ensure early identification of issues and to avoid confrontation and conflict.

With the bulk of research findings, both from this study and other research, indicating net positive benefits of riparian vegetation to both
the agricultural sector and the broader community, the protection of existing areas and re-establishment of degraded riparian vegetation is a growing community expectation.

Water quality issues associated with acid sulfate soils

Forty three percent of respondents offered comments on Acid Sulfate Soils (ASS). 30% of industry advisors who discussed this issue felt it was only a minor issue to the sugar industry in their district of responsibility. Two NSW industry advisors were very positive about best management practices developed through the participative projects in NSW and co-operative work with Queensland and NSW government departments. ASS projects in northern NSW have shown that, given the correct advice and active management, cane growers can minimise acid discharges from these soils.

Conversely, 50% of Departmental advisors and community representatives in the Far North, Burdekin and Mackay were concerned about ASS disturbance, impacts on fish and fish habitat, heavy metal mobilisation, and lack of compliance. The potential to expand into Melaleuca wetlands was seen as a significant ASS risk. Two of these respondents cited recent CSIRO findings from Trinity Inlet, which showed very high oxidation rates at that site and significant downstream impacts. These findings suggest that whilst the extent of area affected by ASS may be less in northern districts, compared to southern districts, the potential release of pollutants and ecological impacts may still remain severe.

Northern districts of the industry are clearly becoming more aware of the issue, however no clear indication of the severity of the problem in northern and central Queensland exists. Hence the wide range of views expressed by respondents. A greater understanding of the extent, behaviour and potential impacts of ASS in these areas is therefore required from future research and monitoring.

Quote: “There is plenty of information available for the industry on how to grow cane on ASS. However there is not enough about avoiding these sites and preventing exposure of these problem soils.”

This quote typifies community representatives’ concerns that whilst research has been conducted to help growers minimise the impacts of cane growing on ASS, there is still a strong push to allow further development of these soils. Many community representatives felt these soils should be avoided, hence preventing any further impacts from ASS.

Water supply management

Contrary to the findings of Chudleigh et al (1997) water supply management issues did not dominate discussions regarding environmental and sustainability issues, with less than 10% of respondents offering comment. Those discussions that did arise generally related to the promotion of water use efficiency for both environmental and economic sustainability, or to water shortages and competition between various land uses for available water allocations.

Water shortages were clearly highlighted as a significant issue in the Bundaberg district with severe pressure on existing surface and groundwater supplies. Although the partial completion of water developments was considered the cause, the industry recognises that water use efficiency will have to be demonstrated across the board before further major capital expenditure will be allocated to water infrastructure.

One industry advisor noted that improvements can still be made, particularly in the plant cane cycle where over-watering still commonly occurs. Increased confidence in and use of weather predictions and irrigation scheduling tools will assist to overcome this and other limitations.

Water infrastructure and allocations for competing water users (including the environment) were seen as an issue by one Mackay community representative. As a result, off stream storages and water re-use were the preferred options for districts undergoing water shortages. However, it was highlighted that construction of such storages on sites of existing wetlands was inappropriate and should be discouraged.

Stakeholder Interaction

In Queensland there appears to be less positive
interaction between industry advisors and community stakeholders than in NSW. NSW extension staff appear to take a more positive view of interaction with the community. This is, in turn, being well received by the NSW community. This situation may be due to past conflicts in NSW that have necessitated the industry’s interaction with stakeholders.

BSES and other advisory staff consider themselves to be a good source of accurate information on the sugar industry and its environmental issues. However they believe they are not recognised by concerned groups as a key contact point, and hence are not regularly approached for information by concerned groups.

Active participation of industry extension advisors in community organisations and programs such as Integrated Catchment Management (ICM), or Total Catchment Management (TCM) in NSW, is clearly much stronger (and effective) in NSW. Advisor involvement in ICM and Landcare activities in Queensland has been on a somewhat ad hoc basis. This involvement will need to increase if industry advisors are to be seen by the community as a reliable information source on environmental issues. The industry will need to determine whether they consider this to be an appropriate role for these staff.

Seventy percent of community and departmental respondents interviewed had received some information from CRC Sugar, much of this very recently, indicating that the CRC Sugar communication program is establishing an effective network amongst these community organisations. The number of environment/community organisations on the CRC Sugar Contacts Database has increased to over 100 in the 12 months to September 1999. A monthly information email is now sent to almost 250 individuals and organisations.

Forty five percent of community group representatives indicated that they considered interaction with the industry in recent times beneficial and productive. However, some representatives noted that some issues have been difficult to address.

Quote: “Usually we will wait to be invited to comment, but we will use the media to raise awareness of issues. We don’t want to threaten the industry, just address some environmental issues, which we see as significant.”

This quote indicates a typical community group attitude. Greater meaningful dialogue between parties at the district level is perhaps the best strategy to help to reduce confrontation.

**Emerging issues and future research / extension needs**

This stakeholder consultation has been very encouraging in that it has helped raise awareness about a range of water-related issues and their importance to the sugar industry and broader community.

Issues the community groups felt needed additional attention in the future included:

1. There is a need to review, and modify where possible, mill by-product recycling practices. Many community stakeholders interviewed were aware of the positives associated with recycling these products. However, they were still critical of current distribution, stockpiling and application procedures. CRC Sugar has initiated a research project to investigate the behaviour of stock piled by-products. Possible impacts of by-product usage on dissolved oxygen in water also needs to be investigated.

2. The industry may benefit from generating greater public awareness of the range of current activities to monitor nutrient inputs, output and/or losses, as a means of promoting sustainable nutrient management.

3. The potential positive impact of recycling effluent water on canelands was recognised. The feasibility of effluent irrigation of sugar cane on the Atherton Tablelands to reduce effluent input into Lake Tinaroo should be investigated.

4. Greater integration and co-operation between sugar industry advisors and State Government Departmental officers may help to address the perceived lack of consistency in departmental policies and decision making.

5. There is a significant difference between community and industry respondents
attitudes towards the values and need to protect/maintain riparian vegetation.

6. The expense of revegetation is seen as a significant issue. Given the increasing expenditure on revegetation, research into more economical and effective techniques may be cost effective.

7. Involvement of Sugar Industry Liaison Officers and local conservation organisations in local land use planning activities should be encouraged in all districts to ensure early identification of issues and to avoid confrontation and conflict.

8. Off-stream water storages are preferred over large on-stream dams by community representatives. However, planning the location of on-farm water storages needs to be reviewed, as existing natural wetlands are considered inappropriate sites.

9. Encourage regular local community forums to allow open discussion of issues, whilst also generating a positive focus on industry initiatives.

10. Active participation of industry representatives and advisory staff in community resource management programs should be encouraged.

Issues raised through the consultation in 1999 are clearly broad ranging and in many cases of considerable concern to the community as a whole. The encouraging aspect is that more people now appear to be better informed and more willing to engage in meaningful debate about a range of water related issues, especially in terms of how they impact on the broader environment. This represents significant progress as many of the water and environment related issues will need input from both the urban and rural communities if they are to be addressed in a meaningful and sustainable way. Every effort now needs to be made to continue educating and engaging the wider community and cane growers to help best manage water in cane growing catchments.

Community Attitudes to Environmental Protection

Some insight into the values placed by the community on water may be gleaned from an understanding of the attitudes towards environmental protection. For example, the retention of wetlands is seen as important in maintaining water quality and aquatic habitat. A number of CRC Sugar activities have investigated the attitudes of growers and the broader community towards the environment. An understanding of these values is important in making land use planning decisions, prioritising research, development and extension activities, and in determining how best to work with stakeholders on related issues. This study focused on the environmental aspects of water resources and has not investigated the many other values associated with water, such as security of supply or demand for drinking water that meets health standards.

While it is relatively simple to estimate the value of sugar cane production, it is far more difficult to place financial values on environmental losses through land clearing. Using a choice modelling approach involving a survey and mathematical analysis, Mallawaarachchi et al (1999) have estimated the value that the Herbert River community places on conserving the region’s environmental assets.

A survey of residents (both those involved in the sugar industry and those not) in the Herbert River District was carried out in June 1998. The survey reveals that the Herbert population has a much greater reliance on the rural sector for employment than the Australian average. 40% of respondents were directly employed in the sugar industry. The results indicate a high level of interest in environmental management issues in this district.

Results of the choice modelling indicate that the Herbert River District community identify significant benefit in protecting riparian and wetland areas but the value placed on tea-tree woodlands is relatively low. The loss of a hectare of tea tree woodland is valued at a cost of $18 per year whereas a hectare of wetland or riparian area is valued at $2800 per year. These value estimates match closely with the area of existing wetlands and tea tree woodlands, where the wetland area has significantly declined due to agricultural development in the
past. Although the area of woodlands has also declined, significant areas of woodlands remain in the district in its natural form. In comparison to these environmental values, one hectare of sugarcane may produce returns as high as $2500/ha/year, while returns from grazing are around $34/ha/year.

Other indications from the survey are:

- 66% favour development and environment in a like manner.
- only 23% of respondents believe that the economic benefits are more important than the impacts of land clearing.
- 60% favour a voluntary incentive to encourage cane growers to preserve native vegetation.
- Only 30% supported the concept of an environmental levy on land rates.
- 70% did not believe that the government could be trusted to spend such a levy to support an incentive scheme for the retention of native vegetation.

These survey estimates have been used in a regional land allocation model along with local soils and other productivity data to investigate options to manage Herbert land resources for greater regional income and better protection of sensitive environmental areas. Such analysis can be used, together with an understanding of local issues, to help maintain farm profits while protecting the natural character and ecological values of the district.

Facilitating Change

CRC Sugar research activities include many activities related to water quality and management. However, the long-term success of any research program is evident not in terms of the findings of these individual activities but in terms of the adoption of improved management practices by stakeholders. To aid this uptake of new technologies, CRC Sugar programs include research into the social aspects of sugar cane production and community values. Participative research activities and extension programs focussed on environmentally sustainable production practices aim to enhance the development and uptake of improved practices.

A variety of factors influence the adoption of new technologies by decision-makers and farmers. These include the loss of flexibility, complexity, economic factors, personal goals, risk and uncertainty. Extension theorists have identified many such ‘barriers to adoption’ that influence the uptake of innovations by agricultural producers. Extension officers are well aware that agricultural producers do not always adopt innovations simply because they are more profitable. This lack of up-take is even more likely with non-commercial (i.e. environmental protection) innovations, which often provide no immediate tangible benefit to the landholder. Where there is little obvious incentive to change, adoption rates are generally lower than for profitable innovations.

To add to the complexity of this issue, the general community may not fully understand problems faced by the agricultural sector, nor the reasons why certain apparently ‘beneficial’ practices are not adopted. There is also a widespread perception that a significant volume of research is available but is not reaching its full potential audience.

Understanding Factors Influencing Growers’ Decision Making

Understanding the attitudes of key stakeholders in the extension process may provide some insight into how to better address these issues. In addition to the stakeholder consultations described above, sociological research within the CRC Sugar is helping to develop an understanding of growers’ attitudes towards the environment and how they seek information and make farming decisions.

Two surveys by students of CRC Sugar and the Central Queensland University have provided an insight into the factors affecting growers’ decision making. Kraak (2000) in her report “Why do growers do what they do?” has investigated farming behaviour and attitudes in relation to crop, soil and water management and their interpretations of ‘sustainability’. Grasby et al (2000) undertook an industry wide social survey of cane growers, compiling information on the demographics and attitudes of growers. These features of the industry are important in understanding the capacity for...
change. While these studies are not limited to water issues, they are important to consider in developing any research and extension program.

Grasby et al (2000) found that three quarters of cane growers have succeeded their parents into the industry. Nearly half are third generation growers or more. However, only 27% of growers’ spouses came from cane growing families. Growers responding to the survey averaged 52 years of age with 27 years growing cane. Education levels are lower than the Australian average with around 60% of growers having ceased their education at the primary or lower secondary level. Female growers have a slightly higher level of education. 20% of growers have tertiary qualifications. Education and literacy levels are important to consider in developing extension strategies.

Kraak (2000) in her smaller ethnographic study of the Mossman/Mareeba area also identified a range of factors that affect decision making by growers, generally dominated by economics and productivity. Personal knowledge, science and technology, expert advice, lifestyle and the physical features of the farm were all elements of decision making. Growers’ own knowledge of the farm and farming practices rated highly as the basis of decision making. Information provided by industry advisers or research programs is taken into consideration in the context of this personal knowledge. Kraack’s research found that risk adversity formed a part of this. All growers valued expert advice, particularly by those who were newer to the industry. Weather was the main feature of the physical context of the farm that affected growers’ decisions. Growers participating in Kraak’s interviews have a strong belief in the benefits of science with a strong reliance placed on research and development. Kraack found that in some cases this can cause growers to become overly reliant on research providing them with a simple solution (such as a wonder variety) to overcome problems.

Both studies identified that the most important lifestyle factor in decision making was the continuation of the ‘family farm’. Industry-wide, some 44% planned to pass the farm on to the children and an additional 24% intended to sell the farm either entirely or partly to their children. Flexibility, ‘being you own boss’ and outdoor work were also important decision making factors. In the Mossman/Mareeba study, older growers were generally more likely to discuss lifestyle as an important factor. Considerable concerns were expressed about the future of the industry and the viability of the family farm.

Kraak and Grasby et al both found that information is sourced in a variety of ways, with face-to-face being by far the most popular. The most valued sources of information are the BSES, CPPB, field days, industry journals and other farmers. As face-to-face was considered such an important mode of obtaining information, it is interesting to ask what growers considered to be desirable attributes of an extension officer. These attributes include: reputation, on-farm experience, time in the community — both to establish a reputation and to be able to localise information, living in the community, open to informal meeting arrangements and consistency of advice from different sources.

Both research projects confirmed findings in other industries that information needs to be ‘localised’ before it will be readily adopted. That is, growers need to be confident that the information applies to their situation. This can be catered for by developing location specific extension packages, incorporating local trials results and information wherever possible. “Hands-on” experience and grower beliefs are highly valued.

Generally, growers were very aware of the issues facing their industry. Many hold a sense of stewardship for the land. However, there were feelings that the industry was not fairly represented in the wider community when it comes to the environmental effects of cane growing. A need to consider the economic impacts to landholders of environmental initiatives and to share these costs was considered important.

As could be expected with individuals, very different attitudes towards farming and sustainability were evident among both growers and industry advisers. These different values are important to consider as very
different outcomes may be visualised from discussions. Kraak undertook interviews in the Mossman mill area — including both Mossman and Mareeba growers. The values of the Mossman growers, generally well established farms differed substantially from those of the Mareeba growers, many of whom were new to the industry and facing considerable establishment costs. This was particularly evident with their attitude towards sustainability as is evident in Figure 8-1.

The majority of growers in Kraak’s small study believe that, overall, cane growers behave in a responsible way to the environment and are doing everything possible to reduce environmental impacts of cane growing. They also believe that it is not necessary to degrade the land in order to grow cane. There were varied responses as to whether growing sugarcane has just as much impact on the environment as other agricultural enterprises. In short, both Grasby et al and Kraack found that the majority of growers believe that they are doing what they can to reduce environmental impacts, of which water quality is a part.

The Need for On-going Support

It is also interesting to consider how much support growers need to continue to utilise practices that have been demonstrated to be beneficial. Is it possible to deliver information about improved management practices and expect growers to adopt them? A survey undertaken by BSES provides an indication that there is need for new technology to be “championed” by an extension officer who will continue to promote the concept and provide grower support (O’Grady and Christiansen, 2000).

The rate of use of irrigation scheduling in the Burdekin is a case in point. Irrigation scheduling refers to the quantity and timing by which water is supplied to the plant’s root zone. Farmers who irrigate use a variety of ways to schedule their irrigation as shown in Figure 8-2 for the Burdekin region. It is evident from these results that the use of physical measurements for scheduling irrigation is fairly low.

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**Figure 8-1**: Differences in priorities in sustainability nominated by canegrowers in (a) Mossman and (b) Mareeba regions in north Queensland (Kraak, 2000)

**Figure 8-2**: Methods used to schedule irrigation in the Burdekin region
reported that in 1994-95, 70% of Burdekin River Irrigation Area (BRIA) growers and 4% of Delta growers utilised evaporation mini-pan’s. These figures increased to 83% of BRIA growers and 48% of Delta growers in 1996/97. So why is it that, despite a potential yield increase of 10-25% (Hardie et al, 2000) and a previous high rate of adoption, this survey indicates that Burdekin growers have stopped using evaporation mini-pan’s?

Holden and Mallon’s survey was undertaken as a final stage in an intensive extension program promoting the use of irrigation scheduling. After this program ended, evaporation mini-pan’s were not promoted as heavily by extension staff. It appears that, even where a clear financial benefit has been demonstrated, growers will only continue to use this tool if it is continually promoted and supported by extension staff. Sutherland (pers. comm.) has suggested the need for tools such as mini-pan’s to be ‘championed’ by a local extension officer.

Another plausible explanation may be that growers have used evaporation mini-pan’s for a few seasons to adjust their irrigation scheduling. After this time they may continue with the scheduling, without using the mini-pan’s to check. Several other tools are available for irrigation scheduling. However, the declining use of evaporation mini-pan’s has not been matched by a great increase in alternative irrigation scheduling tools.

The declining use of evaporation mini-pan’s after the intensive extension program ceased, as indicated by these results, supports the need for on-going extension efforts in supporting new technologies.

Conclusions

The research activities described here have identified some of the values placed by the community, cane growers, industry advisers and researchers towards environmental sustainability and water resources. Water is important to these stakeholders both as a resource for irrigation, drinking, industrial and household supplies and for the protection of natural ecosystems and support of fisheries habitats. The sugar industry must adopt practices to protect both of these values if all stakeholders’ needs are to be met. This is particularly emphasised by the close proximity of the industry to World Heritage areas of the Great Barrier Reef and Wet Tropics.

The knowledge of how growers make decisions is valuable in tailoring research and extension activities towards meeting these objectives.

References


Hunt, R. 1999. Environmental and Sustainability Issues and Extension Requirements of the Sugar Industry. CRC Sugar Internal Report. Activity 0.0.9


9. Conclusions

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It is clear from the preceding chapters that CRC Sugar water related research has delivered significant benefits to the industry and opened a number of opportunities for further work. Much of the success can be attributed to the approach adopted by CRC Sugar, namely, facilitation of multidisciplinary teams, implementation of appropriate integrative frameworks, adoption of participatory approaches with key client groups, and implementation of a systems analysis framework based on a combination of experimentation and modelling. While much has been achieved, future drivers will require that the sugar industry maintain a focus on efficient and sustainable water management practices. Increasing demands for water from all sectors of the Australian economy, together with increasing scrutiny by governments and conservationists to ensure water is used efficiently and profitably, will demand that this happen.

Drivers of change are already well developed, the Queensland Government Rural Water Use Efficiency Initiative and the COAG (Council of Australian Governments) water reform agenda but two examples. The COAG agenda requires a significant shift in the water industry towards one based on commercial principles. Specific issues include:

- the water industry to be based on commercial principles, including privatisation or corporatisation of utilities
- water prices to be based on consumption and to cover all costs of supply
- water rights to be separate property rights from land rights
- markets for the free trading of water rights separately from land rights
- reduction of cross-subsidies in water provision
- specific water allocation to the environment
- integrated catchment management as the vehicle for resource management
- public involvement and consultation

Implementing some of the changes required by COAG may prove challenging, but we are already seeing meaningful change. Planning and management of water is starting to take place within a framework of integrated catchment management involving a partnership among industry, farmers, scientists, conservation groups, and governments. People are engaging in debates as to how water should be viewed and managed, and the search for meaningful environmental flows is underway. The sugar industry is already part of this change process, and it is well placed to capitalise on the outcomes of CRC Sugar research in ongoing efforts to secure and implement more environmentally sustainable water and solute management practices.