CSIRO LAND and WATER

Quantifying and managing sources of sediments and nutrients in low-lying canelands

Project no. CLW007 – Final Report

Prepared by: Christian H. Roth and Fleur Visser

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1. Executive summary

Large areas of the coastal plains of catchments discharging into the Great Barrier Reef Lagoon along Queensland's north-east coast are used for sugar production. Various studies investigating sediment discharge from catchments where sugar is an important land use have demonstrated that sediment export from cane lands often continues to be higher than from adjacent forested areas or other land uses. The main concern with the export of sediments is the loss of associated nutrients, in particular forms of phosphorus and nitrogen bound to the fine sediment fractions (suspended sediments), and the potential harm these materials might cause in rivers, wetlands and near shore marine ecosystems. Many growers are aware of these issues and have proactively engaged in a variety of activities and practices to reduce the likelihood of such environmental impacts, and the widespread adoption of trash blanket harvesting is testimony to this. However, there is still a lack of understanding on the exact amounts and sources of sediments and nutrients leaving cane lands. More importantly, growers lack information on practical solutions to reducing sediment export and where to target the most appropriate sediment control measures.

In response, SRDC funded Project CLW007 with the aim to develop a robust understanding of sediment sources, transport pathways and sinks as the means to better target cane land management towards reducing sediment export. The approach chosen was to develop a sediment budget for representative areas of low-lying cane lands in the Herbert district. This approach has particular advantages for resource management purposes as it ensures that all components in a catchment sediment transport system are examined, so that important sediment sources and transport processes can be identified and management appropriately targeted. The bulk of the study was conducted in a 536 ha large sub-catchment of Ripple Creek in the Lower Herbert, comprising 320 ha of low-lying floodplain soils under sugar and 216 ha of forested uplands. A range of monitoring methods were developed and implemented in order to capture the breadth of processes and to employ the most appropriate methods in each individual situation and best suited to each scale of measurement. In general, the study relied on the following five monitoring strategies:

- Stream gauging to determine sub-catchment sediment discharge
- Paddock scale run-off flumes on ratoon and plant cane fields
- Spatially distributed grab sampling
- Cross-sectional measurements in drains and water furrows
- Erosion pin arrays on headlands and in drain banks

The various monitoring sites were complemented by a series of grower demonstration sites to test a variety of management options with respect to their practicality and benefit in reducing sediment export.

In general, we can conclude that the average export of suspended sediments (clay and fine silt particles) from low-lying cane lands is likely to range between 3 and 4 t/ha and year; a value that is assumed to be reasonably representative of large areas of the alluvial floodplain soils of the Lower Herbert district with more than 2000 mm of annual rainfall. Whilst some uncertainty remains on the absolute sediment export value, the main focus should be on the relative differences between the landscape elements, and the opportunities for further reduction of sediment export from cane land that these results provide. On the basis of the sediment budget, water furrows and plant cane fields were by far the most important source of sediment within the study area (425 and 376 t, respectively), while headlands and minor drains turned out to be the main areas of deposition (105 and 74 t, respectively). These results clearly indicate that cane blocks are not necessarily the main sediment source, and that significant scope exists to minimise sediment export by targeting appropriate management options at other cane land elements.

In this regard, we demonstrate that even simple measures like improved management of headlands and the gradual elimination of water furrows following laser-levelling provide scope for reducing sediment export by as much as 19%. Repairing eroding drain banks can be an equally effective measure, but is likely to be more expensive. Combining improved headland management and elimination of water furrows has the potential to reduce sediment export from low-lying cane lands in the Herbert by about 35%, and if combined with drain bank stabilisation, the level of reduction reaches 50%. This would constitute a significant reduction, and lies within the order of magnitude of targets mooted in the GBRMPA Water Quality Plan of 2001. Hence, achieving such targets can be shown to be quite feasible and is seen to provide a significant opportunity for the cane industry to further improve its environmental performance.

2. Background

Large areas of the coastal plains of catchments discharging into the Great Barrier Reef Lagoon (GBRL) along Queensland's north-east coast are used for sugar production. Before the widespread introduction of green cane trash blanket harvesting (GCTB), many sugar cane areas were reported to have had very high rates of soil loss. Erosion rates in the order of several hundred tonnes per hectare were observed in some of the more hilly cane growing areas in the Mackay and South Johnstone areas (Sallaway, 1979; Prove et al., 1995), reducing to about 10-20 tonnes per hectare when GCTB was introduced (Prove et al., 1995). More recent studies have not been conducted, and there is little information on actual sediment export from flatter, low-lying cane lands in floodplain areas such as are common in the Herbert district.

However, various studies investigating sediment discharge from catchments where sugar is an important land use have demonstrated that sediment export from cane lands often continues to be higher than from other land uses. Apart from loss of soil productivity, soil erosion in cane lands is believed to have increased delivery of sediments to rivers and to the GBRL above natural levels (Neil et al, 2002; Prosser et al., 2002; Rayment, 2002; Reef Science Panel, 2003), even though these levels are assumed to have decreased since the introduction of GCTB. More detailed case studies have been conducted in the Herbert (Bramley and Roth, 2002; Furnas, 2003), Tully (Furnas, 2003) and Johnstone catchments (Hunter and Walton, 1997). The main concern associated with the export of sediments is the loss of associated nutrients, in particular exchangeable forms of phosphorus and nitrogen bound to the fine sediment fractions (suspended sediments).

In the past decades, expansion and intensification of the sugar industry has also coincided with a significant increase in the use of fertilisers, in particular nitrogen and phosphorus (Pulsford, 1993). There is strong evidence that increasing use of fertiliser input in cane lands has led to an increase in discharge of dissolved nutrients in streams and rivers draining cane lands, in particular nitrate and ammonium. This has been particularly well documented for the Tully (Furnas, 2003) and Herbert districts (Bohl et al., 2000, 2001; Bramley and Roth, 2002; Furnas, 2003; Pearson et al., 2003).

Generally therefore, it is now accepted that modern forms of land use along coastal catchments of the GBRL, including sugar production, have led to a significant increase in sediment and nutrient delivery to streams and rivers, with a clear potential to harm freshwater ecosystems (Pearson et al., 2003; Reef Science Panel, 2003).

The harder question to answer is whether the increased delivery of sediments and nutrients to rivers draining into the GBRL is harming the near-shore marine ecosystems (reefs, sea grass beds). This remains a contentious issue. On the one hand, there is clear evidence that turbidity of near-shore sea water brought about by wave re-suspension as a result of the frequent south-easterly trade-winds is likely to be greater than any sediment delivery-induced increase to turbidity, so that some argue that any increase in sediment delivery is not likely to have a detrimental effect (Larcombe and Woolfe, 1999).

Increased levels of sediments and nutrients are not likely to have direct impacts, but there is evidence that increased levels of nutrients (in particular dissolved nitrogen) in combination with a change in the composition of suspended sediments will reduce the ability of corals to recover from damage caused by natural events such as bleaching and cyclones (Wolanski, 2001). These synergistic effects between nutrients and suspended sediments form so-called 'marine snow', which has been shown to have a detrimental impact on the recruitment of corals (Fabricius and Wolanski, 2000). In summary, there is now widespread consensus amongst leading scientists in the region that if unchecked, further increases in the rate of sediment and nutrient delivery to the GBRL will adversely impact near-shore reefs and seagrass beds (Williams et al., 2001; Reef Science Panel, 2003).

This is borne out by evidence from overseas (Hawaii and Florida), where decline in reef systems has been clearly associated with nutrients originating from terrestrial runoff; there is also evidence that this decline is irreversible by the time nutrient accessions had been irrefutably linked to reef decline (Reef Science Panel, 2003). As a more in depth discussion of this highly complex topic is beyond the scope of this report, the reader is referred to some of the more detailed reviews on this issue (Reef Science Panel, 2003; Furnas, 2003).

Against this backdrop of major national debate, the sugar industry has been under pressure to demonstrate that it is taking measures to minimise its potential impact on waters draining into the GBRL. At the same time, there is also increasing awareness of the need for Australian rural industries to be productive, but not at the expense of degrading our natural resources so as to impair their capacity for use, including use by future generations. This need has been enunciated in the principles of ecologically sustainable development and the production of “clean and green” agricultural products. So, the issue of soil erosion and sediment and nutrient export is not just a question about impacts on the GBRL, but needs to be seen within the broader context of sustainable sugar production, which includes retaining the integrity of the land resource as the main basis for cane production. Hence, minimisation of soil erosion is as much about maintaining future productivity as it is about limiting off-site impacts.

As a result of this, the industry has demonstrated a desire to minimise the potential environmental impacts of sugarcane production, through publication of the *Code of Practice for Sustainable Cane Growing in Queensland* (CANEGROWERS, 1998). However, it is not yet clear what impact this initiative has had in practice. The NSW industry has developed a process of self-regulation for control of acidic discharge from acid sulphate soils (Beattie et al., 2001). These initiatives provide guidance to interested growers on best practice environmental management. More recently, the sugar industry has developed a process by which growers can self assess and rate their environmental performance as the basis for future improvement using an interactive workbook called COMPASS (CANEGROWERS, 2001). Many growers are also aware of these issues and have proactively engaged in a variety of activities and practices to reduce the likelihood of environmental impacts, and the widespread adoption of trash blanket harvesting is testimony to this. However, there is still a lack of understanding on the exact amounts and sources of sediments and nutrients leaving cane lands. More importantly, growers lack information on practical solutions to reducing sediment export and where to target the most appropriate sediment control measures.

This lack of understanding of key processes and the paucity of information regarding practical solutions are seen as significant impediments to developing more appropriate and better targeted cane management practices aimed at reducing sediment and nutrient export from cane lands. In response to this, SRDC and the CRC for Sustainable Sugar Production initiated several linked research projects that focussed on the Lower Herbert district. Project BS181 (Integrated drainage management) was directed at better understanding surface flow processes in low-lying cane lands as a basis for better managing inundation and waterlogging. In conjunction with project 2.5.3.1 of the Sugar CRC (Improved drainage criteria), project BS181 provided the basic understanding of surface hydrology in low-lying cane lands (e.g. Mitchell et al, 2001; Post et al., 2001), a fundamental prerequisite to improve our understanding of sediment and nutrient discharge as part of SRDC project CLW 007. Project CLW007, which is the subject of this report, builds on previous CSIRO and CRC funded work (Bramley and Roth, 2002) and on the hydrologic understanding generated by BS181 and CRC 2.5.3.1 to develop a robust understanding of sediment sources, transport pathways and sinks as the means to better target cane land management towards reducing sediment export. Finally, the fate of nitrogen and the impact of sediments and nutrients in freshwater ecosystems of the Herbert has been studied in conjunction with this project through associated projects funded by the CRC for Sustainable Sugar Production (Project 1.1.2; Bohl et al., 2000, 2001) and SRDC (Project JC014 - Quantification of effects of cane field drainage on stream ecology; Pearson et al., 2003).

3. Objectives

The overall objective of the project was to identify sources of sediments and nutrients leaving cane land as opposed to cane paddocks, to refine the current management practices and further reduce sediment and nutrient export from low lying cane lands prone to frequent runoff.

The following three specific objectives underpin the above general objective:

1. Analyse cane farming systems in representative areas of the Lower Herbert district with respect to the relative importance of different field components (plant beds, in-field drains, headlands, main drains) for sediment and nutrient generation.

2. Develop and evaluate additional means of minimising soil loss matched to the respective sediment sources.

3. Produce a soil loss survey manual and provide guidelines for integrated control of soil loss from low-lying cane land.

Statements of achievement against objectives:

1. **Achieved.** A very thorough analysis was conducted for a 536 ha area in Ripple Creek sub-catchment, Herbert district. This area is considered to be representative of large areas of low-lying cane lands in the Herbert district. The analysis has been documented in detail in the PhD Thesis submitted by F. Visser. This thesis, which constitutes the principal output from this project was submitted to the Australian National University, Canberra in December 2002, and copies are provided together with this report. The core of the thesis is the quantification of all key sediment sources, pathways and sinks using a sediment budget. A summary of the thesis methodology and results are presented in sections 4.1 – 4.3 and 5.1 – 5.2 of this report. This sediment budget is one of a very few to have been developed for a floodplain situation and to have been coupled to an analysis of uncertainty, which represents a significant scientific advance in the field of quantitative geomorphology.

2. **Achieved.** Through the establishment of grower demonstration sites, the conduct of field days and many grower workshops, we were able to develop and test a range of practical management options designed to reduce sediment export from cane lands taking a targeted approach by focussing on the key sediment sources or by enhancing the most efficient sediment sinks, as identified by the sediment budget. Some of these recommendations have already been disseminated through a series of presentations in grower meetings in the Herbert, Tully, Mulgrave and Mossman districts. Earlier versions of the recommendations were incorporated into the Integrated Drainage Management Plan developed for the Ripple Creek area as part of the Sugar Industry Infrastructure Package for the Lower Herbert (Roth et al., 2001). A revised set of recommendations are presented in this report in section 5.3, followed in section 5.4 by an example of how these recommendations can be applied in the context of achieving future sediment export targets.

3. **Achieved.** Following the project review, which was carried out together with the companion project BS181, rather than produce a stand alone soil loss survey manual it was decided to integrate the guidelines for managing sediment export into a surface drainage management manual. Whilst this manual has not yet been finalised (components from BS181 are in the process of being included), guidelines to recognise soil erosion from headlands and drains have been drafted, together with a suite of management recommendations for each cane land element. Earlier versions of the recommendations were incorporated into the Integrated Drainage Management Plan mentioned above (Roth et al., 2001), and a revised set of recommendations is presented in this report in section 5.3. Once it has been approved by SRDC, it is planned to modify this report into a stand alone, more grower friendly document and to disseminate it widely via the CSIRO Land and Water website (see also section 9 of this report).

4. Methodology

Details of the methodology utilised are provided in the PhD thesis prepared and submitted by Fleur Visser to ANU as part of this project (Visser, 2003). A copy of the thesis is provided together with this report. A summary of the key considerations leading to the selection of methodological approach, the study sites and monitoring techniques is provided in the following sections. These techniques were developed and tested following a series of preliminary tests carried out in the wet season 1998-1999. The actual sediment budget was obtained from detailed measurements carried out during the wet seasons 1999-2000 and 2000-2001. Information on practical management options was obtained from a series of grower demonstration sites established in conjunction with the sediment budget study following the preliminary investigations.

4.1 General Approach

When sediment is transported through a landscape it is not on the move continuously. At the field scale soil particles detached by rainsplash or flowing water will be transported down slope by overland flow. When during transportation the overland flow conditions change, for example reduction of flow velocity due to a change in slope or reduction of overland flow volume due to infiltration, particles can be deposited. The deposited sediment remains stored in the landscape for variable lengths of time. Transport could continue at the onset of a new rainstorm, but the sediment could also become buried by additional material and subsequently fixed by vegetation. When the sediment is fixed it will only be remobilized after a longer period of time as a result of some major 'disturbance' (e.g. a change in land-use or stream incision).

Due to the variable patterns of storage and remobilization of sediment, catchment yield is usually smaller than the erosion rate in a catchment. The discrepancy can be described as the catchment Sediment Delivery Ratio (SDR):

SDR = Catchment yield / Gross catchment erosion.

Both catchment yield and SDR are emergent properties of a catchment system, resulting from the interactions of many individual components.

The movement of material through a river catchment can be thought of as a complex system; that is, a system with many components and agents that interact in many ways. It is well known that complex systems cannot be understood by examining their emergent properties alone (e.g. yield or SDR), and require a whole system perspective (De Boer and Ali, 2002; Wasson, 2002). Such a perspective is provided by sediment budgets. A sediment budget is an accounting of the various sediment sources in a catchment and the possibilities of storage when the sediment is routed through that catchment, which results in the catchment sediment yield (Reid and Dunne, 1996; Knighton, 1998).

Leopold *et al.* (1966) and Dietrich and Dunne (1978) are some of the earliest authors of sediment budgets. Since then numerous researchers have applied this approach, which provides a convenient means of presenting and analyzing erosion, deposition and sediment yields of river catchments (Walling, 1999). The sediment budget approach has particular advantages for resource management purposes. The budget principle ensures that all components in a catchment sediment transport system are examined, so that important sediment fluxes can be identified and management appropriately targeted. In addition it can provide information about the interactions between components of the system and therefore an understanding of how the system will respond to changes (Reid and Dunne, 1996).

Viewed from a geomorphic perspective, cane land consists of a variety of different landscape elements:

- Fields (ratoon and plant cane)
- Headlands
- Drains (water furrows within fields; farm drains, main drains)

Each of these elements has the potential to be either a source or store of sediment. Knowledge of the magnitude of both the erosion and deposition capacity of each landscape element is important for the management of sugarcane land. Besides reduction of erosion from sources in the landscape, the trapping capacity of other landscape elements could be managed to reduce sediment concentrations in the cane land runoff.

A sediment budget study can aid soil management in sugarcane land by showing the relative importance of the various landscape elements as sediment source and the importance of deposition of the material elsewhere in the catchment. The budget balance can confirm adequate representation of processes in the sugarcane landscape or reveal unexpected sources as well as budget errors.

To create a balanced budget all sources and sinks in the studied area have to be known. In the case of low-lying cane land the important sources and sinks are not clear, because prior research has not been done. From what is known from the literature and field observations, all cane land elements have the potential to be either a source or a sink of sediment, and in many cases both. Thus, erosion and deposition processes have to be quantified separately for each individual element and are separately included in the budget equation. The general budget equation is for this particular approach is:

$$I - S = O \qquad \text{Eq. 1}$$

in which I is the amount of sediment input into the drainage system from each landscape element, S is the amount of deposition within each landscape element and O is the total output of sediment from the studied area.

Figure 1 illustrates the initial budget. The question marks indicate the information that is needed to establish the budget.

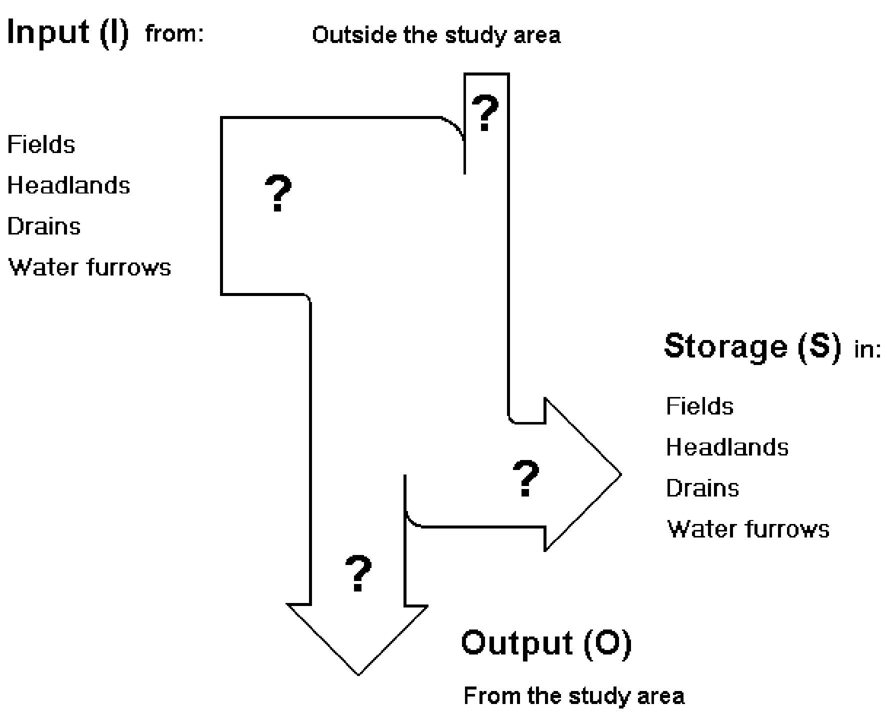

Figure 1: Sediment budget outline for low-lying sugarcane land.

Because there is not sufficient knowledge of the erosion and deposition processes within each landscape element, the methods used to measure these processes should cover the total route of sediment transport through each element and record both erosion and deposition processes along that route. If this is not done properly, sources or sinks could remain unidentified and the budget will be unbalanced. In the drain landscape element, for example, material can erode from the drain bank and be directly transported to the catchment outlet by the drain water. It is however possible that the eroded material from the banks is deposited on the drain bed. The measurement method applied to estimate budget components I and S for landscape element 'drain' must be able to distinguish and quantify both the erosion (from the banks) and subsequent deposition (on the drain bed).

Properties of each landscape element, such as soil type, slope or morphology will vary in space. Examples are differences in the shape of drains or changes in the slope of headlands. The variation in such properties will have an effect on the magnitude of erosion and deposition processes. Less vegetated headlands are for example likely to be more erodible. If spatial variation within landscape elements is not accounted for in the quantification of budget components, the relative importance of processes in landscape elements could be misinterpreted and compromise the budget results.

It is important that the budget is calculated over a short, recent time period. If farmers want to take action now and stop the degradation of cane land they need to know where sediment is coming from under present conditions. An average of processes acting over periods longer than ten years back will not be useful, because agricultural practices and environmental condition have changed a great deal over that period of time. Also, all components have to be quantified for the same period of time. If, for example, one side of the sediment budget equation consists of catchment output averaged over 10 years, the other side of the equation should not be derived from average erosion and deposition rates in drains over only the last two years. The density of the drainage systems might have increased considerably over ten years. Consequently the average discharge over 10 years does not reflect the current contribution of the drainage system to the sediment budget and will create a budget imbalance.

4.2 Study Sites

To obtain a closed budget, the area described by the budget has to be spatially well defined. There should be no sediment transport across the boundaries of the budget area, unless these can be quantified. In reality, catchment boundaries in a floodplain situation such as the Herbert are not necessarily static, and depending on levels of inundation and flooding during major rainfall events, they can vary. This poses a significant challenge to closing a budget.

Within the Herbert floodplain, Ripple Creek is one of the sub-catchments coming closest to meeting the above requirements and at the same time being located in the more humid part of the district. For practical reasons such as accessibility, equipment requirements and combination of landscape elements, it was decided to develop a budget for only a representative part of the Ripple Creek sub-catchment. The chosen site consists of a 5.4 km^2 sub-catchment in the westernmost corner of the Ripple Creek Catchment. For the purpose of this study the sub-catchment is called the Ripple Corner Catchment. It includes a distinct flat segment of the alluvial plain (3.2 km^2) bordered on the south by the Herbert River and on the north by the forested hills of the Mount Leach Range. All of the lowland is in use for sugarcane cultivation apart from farm buildings and some fields with occasional pumpkin and melon cultivation.

The low-lying part of the study area is representative of large sections of the Lower Herbert floodplain and therefore any sediment budget developed for Ripple Creek is deemed as being applicable to similar areas in the Herbert. Ripple Creek sub-catchment is drained by a major drain, known as Ripple Drain, which discharges into Ripple Creek approximately 12 km east of the study area. Figure 2 provides an overview of the sediment budget boundaries and the location of some of the key monitoring sites.

To test the representativeness of the erosion and deposition rates for selected cane land elements, we also established a number of additional monitoring sites outside the actual budget area boundaries. Most of these sites were also located in places where we established the grower demonstration sites. These included headland monitoring sites located further downstream in Ripple Creek sub-catchment and a number of sites established in the Upper Stone area on contrasting soils and on steeper drains (Table 1).

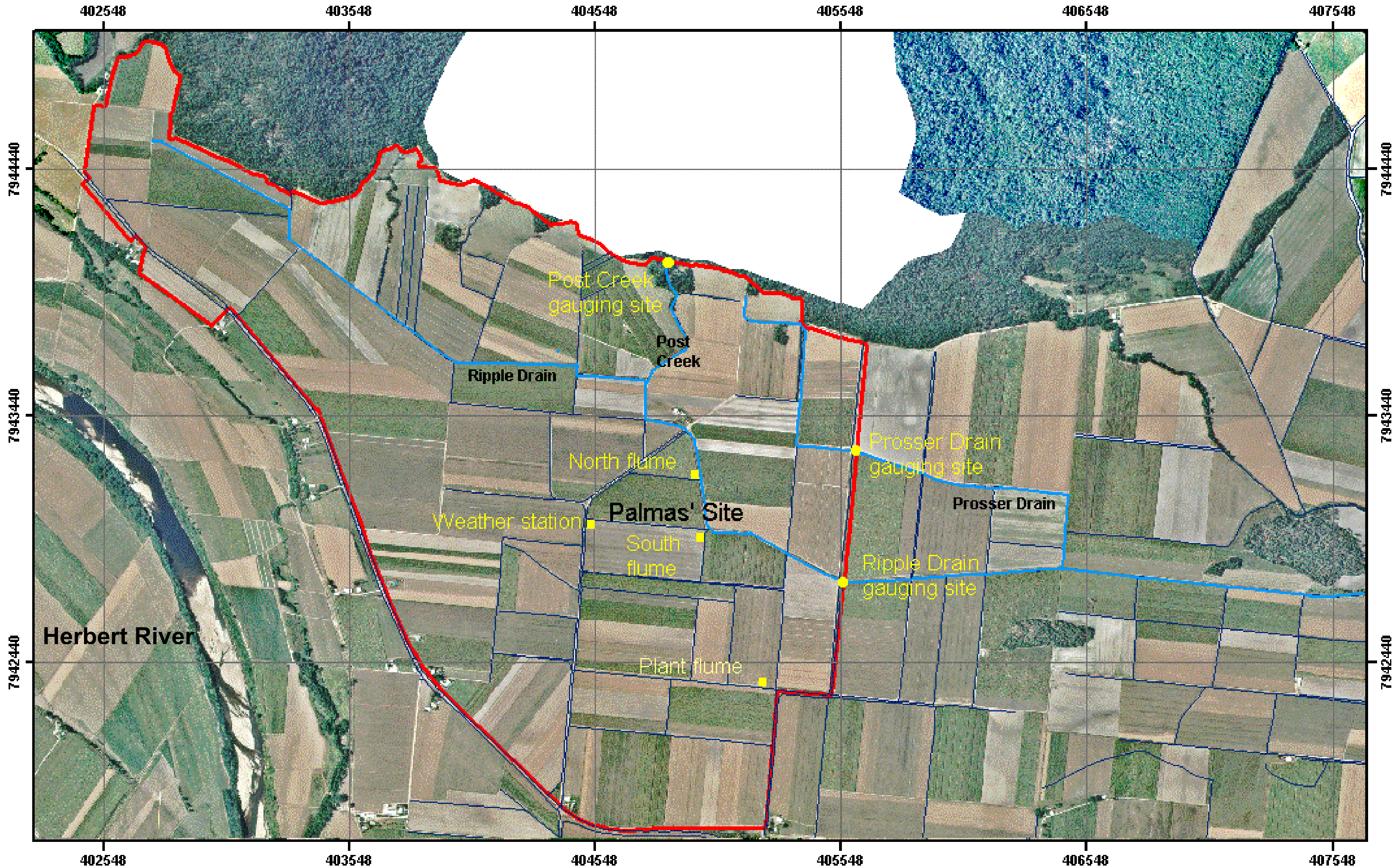

Figure 2: Aerial photo of the study area for the sediment budget study. The boundary of the cultivated lowland is indicated in red and the forested component of the study area is shaded in white. The Herbert River can be seen in the lower left portion of the figure.

4.3 Monitoring Methods

A range of monitoring methods had to be developed and implemented in order to capture the breadth of processes and to employ the most appropriate methods in each individual situation and best suited to each scale of measurement. Details are provided by Visser (2003). Broadly speaking, five general monitoring strategies were employed:

- Stream gauging to determine sub-catchment sediment discharge
- Paddock scale run-off flumes on ratoon and plant cane fields
- Spatially distributed grab sampling
- Cross-sectional measurements in drains and water furrows
- Erosion pin arrays on headlands and in drain banks

Stream gauging sites were established on one of the creeks draining the forested hillslopes ('Post Creek" site in Figure 2) and on the outlets of the study area ('Prosser Drain' and 'Ripple Drain' in Figure 2). The forested site was required to determine the input of sediments from the hillslope areas adjacent to the cane lands. In the second case, the gauging sites were required to quantify the total load of suspended solids leaving the budget area (the term O in equation 1). The sites were shared with the SRDC Integrated Drainage Management project (BS181) for the purpose of determining drain flow and provide calibration points for the MIKE 11 surface flow model as part of the drainage network optimisation work carried out in BS181.

Each gauging site was equipped with a flow depth sensor, a flow velocity sensor and a turbidity probe. Flow discharge was determined on a continuous basis as the product of flow depth and flow velocity for the known drain cross-section at the gauging sites. This was considered the best option, as in floodplain situations backwatering during major flow events can lead to instances of 'reverse flow', so that conventional rating curve or weir methods are not applicable. Sediment discharge was determined by establishing a calibration curve between the turbidity readings and measured concentrations of suspended solids obtained in the laboratory from grab samples collected at the gauging sites, and then calculating the product of flow discharge and sediment concentration derived from the turbidity records.

Large, field scale run-off flumes were utilised to determine the field scale loss of sediment. In any year, one flume was located on a ratooned paddock, and one on a plant cane block. Locations of the flumes are shown in Figure 2. Again, these were sites shared with project BS181. These flumes, which captured runoff across about 20 rows of cane (with a water furrow in the middle in the case of the ratoon field), were equipped with flow depth sensors, flow velocity sensors and auto-samplers to collect samples for sediment and nutrient analysis. Sediment charge was calculated in a manner similar to the gauging sites.

Sampling of drain water for the determination of sediments and nutrients was complemented by a spatially distributed grab sampling routine. After or preferably during major flow events, grab samples were collected at selected points in the study area with the aim of obtaining information on the spatial variability of water quality parameters. Samples were mainly analysed for turbidity (as a surrogate for concentration of suspended sediments). Sampling points were selected to represent a range of landscape elements on the main soil types.

Cross-sectional measurements were used in the water furrows and drains. The method consists in installing two permanent support pins, onto which a profile meter is placed. A measurement rod that can be slotted into holes along a datum bar of the profiler allows heights to the ground surface to be recorded at different intervals before, during and after the wet season. Increases in height of the measuring rod correspond to net deposition; decreases in height with respect to the datum bar correspond to net erosion. Figure 3 provides an overview of the set-up, and Figure 4 provides a sample of data collected for a water furrow on grey sandy soil. A total of 56 cross-sections were established in 99-00 to represent a broad range of water furrows (in ratoon and plant blocks, for different soils), minor drains (flat spoon drains), major farm drains (conventional, steep-walled drains) and the area's main drain (Ripple Drain, see Figure 2). On the large drains, the cross-sections were complemented by erosion pin arrays inserted horizontally into the drain wall. Details on locations are provided in Visser (2003).

Direct measures of erosion and deposition on headlands were undertaken using erosion pins. Each erosion pin array consisted of 35 – 45 pins inserted into the soil (5 X 7 or 5 X 9; 50 cm distance between pins). Height from the top of the pin and the soils surface is monitored at the beginning, during and at the end of the wet season. If erosion occurred, the height difference increases; in the case of deposition, the height difference diminished with respect to the pre-wet season baseline. An example of the layout of an array and the output generated is shown in Figure 5. Between 13 and 7 sites were located in the 99-00 and 00-01 wet seasons, respectively. Sites were selected to represent a range of soils and cover levels adjacent to plant, ratoon and different drain types.

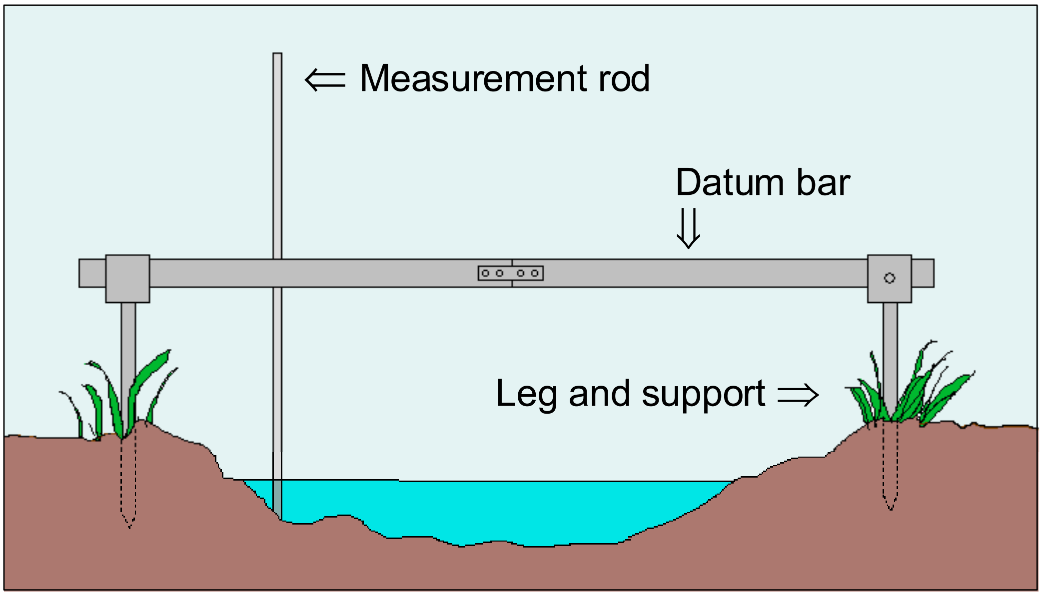

Figure 3: Schematic representation of the surface profile meter.

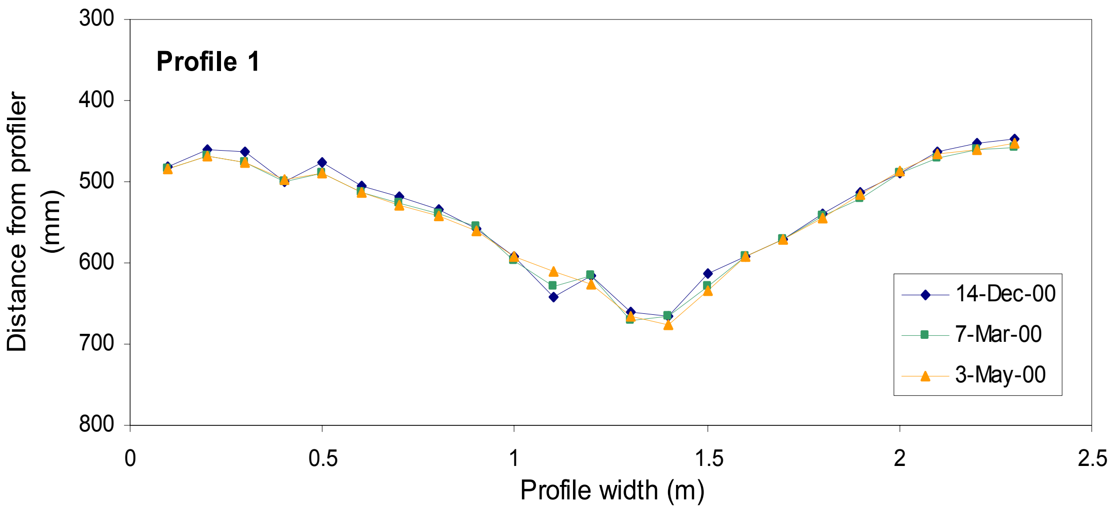

Figure 4: Example of a surface profile through a water furrow in a ratoon field on grey sand.

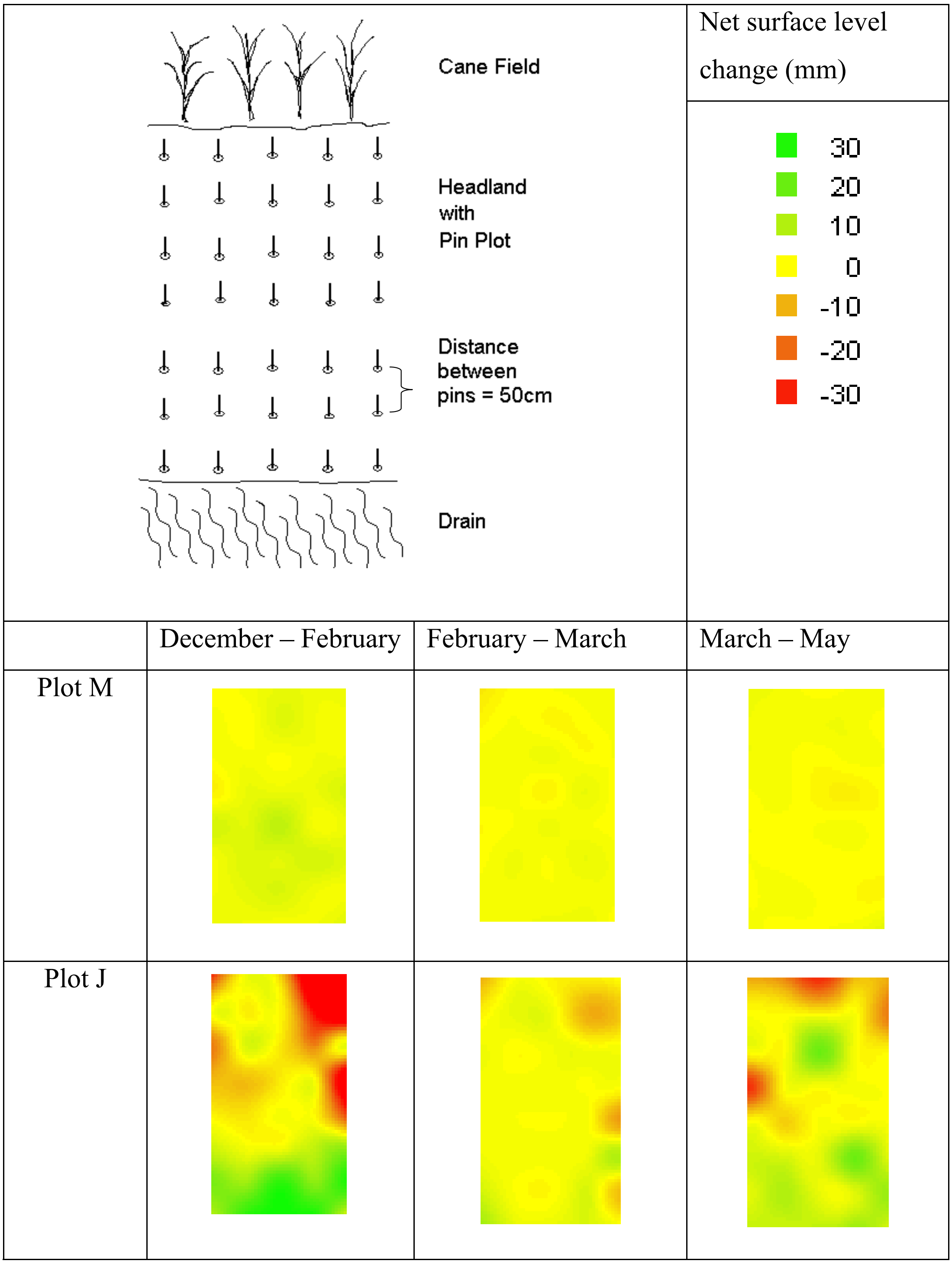

Figure 5: Example of erosion pin array set-up and output showing spatial distribution of net surface level change for a plot with little change (M) and one plot with net erosion (J) during the 99-00 season.

4.4 Grower Demonstration Sites

The preliminary investigations in 1998-1999 enabled us to identify likely key sources and sinks of sediment in low-lying cane lands. On the basis of these results, we designed and implemented a series of grower demonstration sites to test a variety of management options with respect to their practicality and benefit in reducing sediment export. Information on the sites, the activities carried out at each site and the landscape element targeted at each site is summarised in Table 1.

Table 1: Overview of grower demonstration trials, their site characteristics, the management options tested and the monitoring methods employed.

Site name and location	Soil type / landform	Caneland component studied	Treatments imposed	Monitoring methods
1. Gilbert; about 4km downstream of study area, on Jap Creek drain	Silty clays to clays on Ripple Ck alluvial soils	Disturbed headlands on plant cane paddock; shallow farm drains	Active planting of couch grass and Lamendra to re-establish cover versus natural revegetation and bare patches;	Erosion pin arrays comparing revegetation treatments to control
2. Fortini; various sites on Sandy Ck (upper Stone River); upper reaches of Cattle Ck	(Sodic) duplex soils on hillslope colluvial deposits	a. Headlands; spoon drains b. Minor drains c. Major drains	a. Facilitation of natural re-establishment of grasses; planting of couch on disturbed spoon drains and headlands b. Drop structures, flow barriers c. Drop structures; bank stabilisation with rock/earth mixtures; facilitation of natural regrowth; tree planting	a. Erosion pin arrays comparing revegetation treatments to control and profiler cross-sections b, c. Visual assessments and ratings; photographic documentation
3. Jap Creek; Section of Jap Creek drain 2 km east and west of Gangemi Rd	Silty clays on creek deposits and floodplain	Major drain (former Jap Creek)	Reshaping of drain bank, followed by revegetation of drain banks with shrubs and trees selected with respect to root systems and canopy structure to maximise bank stabilisation and minimise interference with harvesting	Determination of drain cross-sections; visual assessments and ratings; photographic documentation

5. Results

A detailed presentation of the results and a thorough error analysis of the sediment budget study has been provided by Visser (2003). In this section, we only present the key data and findings, in particular as they relate to the achievement of the project objectives.

5.1 Total Sediment Output from Study Area

Sediment output was monitored at both outlets of the study area ('Ripple Creek Corner Catchment'; Figure 1) for the wet seasons 1999-2000 and 2000-2001. In both cases, the wet season monitoring season went from December to May. In 1999-2000, Dec-May rainfall was 2740 mm, which is well above the long-term average of 1807 mm and constitutes the tenth most humid Dec-May period on record. Conversely, the 2000-2001 Dec-May period was exceptionally dry, with 1349 mm. The two-year average of 2045 mm is therefore only slightly higher than the long-term average, and therefore it can be assumed that an average sediment budget generated during the study period comes close to the average rainfall conditions.

The sediment discharge values derived from this monitoring are summarised in Table 2. Total sediment load at the Ripple Drain outlet was 1580 t and 1120 t of suspended sediments for the 1999-2000 and 2000-2001 wet seasons, respectively. This corresponds to a unit area sediment discharge of 4.9 and 3.5 t/ha. Note that these are load estimates for suspended sediments only (particles <20 μm) and do not include the bedload fraction. Bedload was not determined, partly because of intractable methodological problems but also because in a floodplain environment the bedload fraction would only move very slowly (in pulses) and constitute a smaller fraction of the total sediment load. However, it does mean that the results in Table 2 represent an underestimate of total sediment export. Monitoring was also discontinued during the June-November period, possibly leading to additional underestimates.

Indeed, the focus on suspended sediments is deliberate, as it is the fine sediments that are associated with nutrients and nutrient export being the prime concern in terms of impacts on aquatic ecosystems. Most of the phosphorus is bound to these particles, and any fine sediment that leaves the landscape takes a substantial amount of phosphorus with it. Whilst nitrogen is also bound to fine soil particles, a greater proportion is also dissolved in the form of nitrate or ammonia that may or may not be associated with fine sediment particles (as demonstrated by the recent results of SRDC project JC016; Pearson et al., 2003; see also Figure 19 in section 5.4 of this report). Hence, control of sediment loss from cane lands is likely to significantly reduce the phosphorus losses, whereas measures to control sediment loss need to be complemented by other measures to ensure nitrogen export form cane lands is minimised.

Table 2: Summary of best estimates of suspended sediment load, discharge values and runoff coefficients for the two outlets ('Ripple Drain' and 'Posser Drain").

	Ripple Drain		**Prosser Drain**	
	99-00	00-01	99-00	00-01
Total Discharge (10^6 m^3)	9.5	7.0	1.6	1.7
Total Rainfall (10^6 m^3)	11.7	8.8	0.9	0.7
Runoff Coefficient	0.8	0.8	1.6	2.3
Sediment load (t)	1580	1120	170	-
Sediment load (t/ha)	4.9	3.5	3.7	-

Data for the Prosser Drain outlet is very uncertain, as shown by the unrealistic runoff coefficients in Table 2. This is due to equipment failures and because of uncertainties in relation to the monitoring of flow in small drains (see Chapter 5 in Visser (2003) for a more detailed discussion). Given that the Prosser Drain only drains about 10% of the study area, this data was excluded from further analysis and not included in the sediment budget.

Strictly speaking, the loads presented in Table 2 do not represent sediment export from cane land *per se*, as they include a substantial amount of sediment input from the forested upland portions of the study area. As shown in Table 3, the load derived for the 'Post Creek' gauging site was 72 t and 56 t for each season, corresponding to unit area sediment loads of 1.1 t/ha and 0.9 t/ha, respectively. Hence the relative unit area contribution of cane land to the load at Ripple Drain outlet in the 1999-2000 wet season lies somewhere between (1580-243)/320 = 4.2 t/ha (in the unlikely case that all of the sediment discharged from the forested areas makes it through to the outlet) and 1580/320 = 4.9 t/ha (if we assume the equally unlikely scenario of all forested upland sediment being stored in the receiving cane lands of the study area). The equivalent range for the 2000-2001 season would be 2.9 t/ha and 3.5 t/ha. Assuming a more realistic case that about half of the sediment originating from the forested hillslope areas propagates though the system to the outlets, net unit area suspended sediment export from cane land is likely to range between 4.65 and 3.25 t/ha. These are comparatively low values considering the high runoff coefficients and high rainfall of the study area and probably reflect the flat topography and the fact that much of the cane land is being trash-blanketed.

5.2 Sediment Budget

The extensive data obtained from the direct measurements of soil erosion and deposition in each landscape element have been aggregated and assembled into the sediment budget shown in Table 3. The relative areal extent of each landscape element within the cane land portion of the study area that was used to extrapolate the net erosion/deposition rates to total loads (t) in Table 3 is provided in Table 4.

Several general observations can be drawn from Table 3. For all landscape elements where both erosion and deposition data was acquired there is a clear indication that both processes occur simultaneously. The balance between the two determines whether a landscape element is a net source or a net sink for sediments. Across the two seasons monitored, minor drains were consistently acting as sediment sinks. Conversely, water furrows, ratoon and plant cane fields were consistently seen to be net sediment sources. The other elements varied between the two years. However, on average, headlands and Ripple Drain also act as net sinks.

Based on unit area values (t/ha in Table 3), on average water furrows and major farm drains are the main source of sediments (net erosion rate 19 t/ha and 9 t/ha, respectively) and minor drains are clearly the most efficient sinks (net deposition rate 35 t/ha). However, once the areal extent of each element is accounted for by multiplying the unit area net erosion or deposition rate with the respective areas in Table 4, the ranking of sources and sinks shifts somewhat. Water furrows and plant cane fields by far constitute the most important source of sediment within the study area (425 and 376 t, respectively), while headlands and minor drains turn out to be the main sinks (105 and 74 t, respectively). These results clearly indicate that cane blocks are not necessarily the main sediment source, and that significant scope exists to minimise sediment export by targeting appropriate management options at other cane land elements, e.g. the elimination of water furrows in the course of laser-levelling blocks with water furrows.

A more in depth scrutiny of individual erosion and deposition rates presented in Table 3 reveals further potential options. The greatest unit erosion rate is consistently observed in Ripple Drain (84 and 87 t/ha in 1999-2000 and 2000-2001, respectively; Table 3) followed by the major drains. These high erosion rates are associated with pronounced bank erosion brought about by the often bare and steep walls of larger drains. Figure 6 illustrates this point, showing a major drain with active bank erosion on one side, and negligible signs of erosion on the other, flatter and vegetated side. This interpretation is further corroborated by the results of the extensive drain survey conducted as part of BS181 in the same area in 1997. These results are shown in Figure 7 and show that the incidence of erosion is far higher for conventional, steep-walled drains when compared to fully vegetated, flat drains. On balance however, major drains still act as net sinks because of the significant level of sediment deposition occurring on the drain beds; changing bank slope in conjunction with the establishment of ground cover on the drains banks could however greatly enhance the net trapping efficiency by significantly reducing bank erosion.

Table 3: Sediment budget for suspended sediments (particles <20 µm) for the study area ('Ripple Creek Corner Catchment'; 536 ha) based on averages (for details see Visser, 2003). Positive values denote deposition, negative values erosion. Bold values are net erosion or deposition.

Source	1999-2000 season		2000-2001 season		Average	
	t/ha	t	t/ha	t	t/ha	t
Headlands erosion	13	297	11	244	12	271
Headlands deposition	26	576	7	157	17	367
Headlands net	**13**	**297**	**-4**	**-87**	**5**	**105**
Water furrows erosion	36	738	48	1181	42	960
Water furrows deposition	18	369	27	664	23	517
Water furrows net	**-18**	**-369**	**-20**	**-480**	**-19**	**-425**
Ripple Drain erosion	84	184	87	190	86	187
Ripple Drain deposition	113	246	95	207	104	227
Ripple Drain net	**29**	**62**	**8**	**16**	**19**	**39**
Major drain erosion	84	289	36	124	60	207
Major drain deposition	29	98	75	258	52	178
Major drain net	**-56**	**-191**	**39**	**134**	**-9**	**-29**
Minor drain erosion	24	51	17	35	21	43
Minor drain deposition	41	86	69	147	55	117
Minor drain net	**17**	**35**	**53**	**112**	**35**	**74**
Ratoon fields	**-1.4**	**-157**	**-0.7**	**-114**	**-1.1**	**-136**
Plant cane fields	**-5.9**	**-644**	**-1.7**	**-107**	**-3.8**	**-376**
Fallow *(estimated)*	**-3.7**	**-110**	**-1.2**	**-38**	**-3.1**	**-74**
Upland	**-1.1**	**-243**	**-0.9**	**-189**	**-1.0**	**-216**
Total (Input - Storage)		-1320		-753		-1037
Ripple Drain Output Table 2)		1580		1120		1350
Difference		260		367		314

Table 4: Areal extent of different landscape elements in the cultivated cane land portion of the study area (total area 320 ha).

Landscape element	1999-2000		2000-2001	
	%	ha	%	ha
Headland	6.9	22.0	6.9	22.2
Water furrow	6.4	20.4	7.7	24.8
Ripple Drain	0.7	2.2	0.7	2.3
Major drains	1.1	3.5	1.1	3.5
Minor drains	0.7	2.2	0.7	2.3
Ratoon field	36.4	116.2	48.9	157.3
Plant cane field	34.1	108.9	19.6	63.0
Fallow	9.4	30.0	9.9	31.8
Other	4.6	14.7	4	12.9

Figure 6: Example of simultaneous erosion and deposition in a major drain. Right: steep-walled drain bank actively eroding; left: flat and vegetated bank stable. Significant amounts of bed deposition taking place in the drain itself.

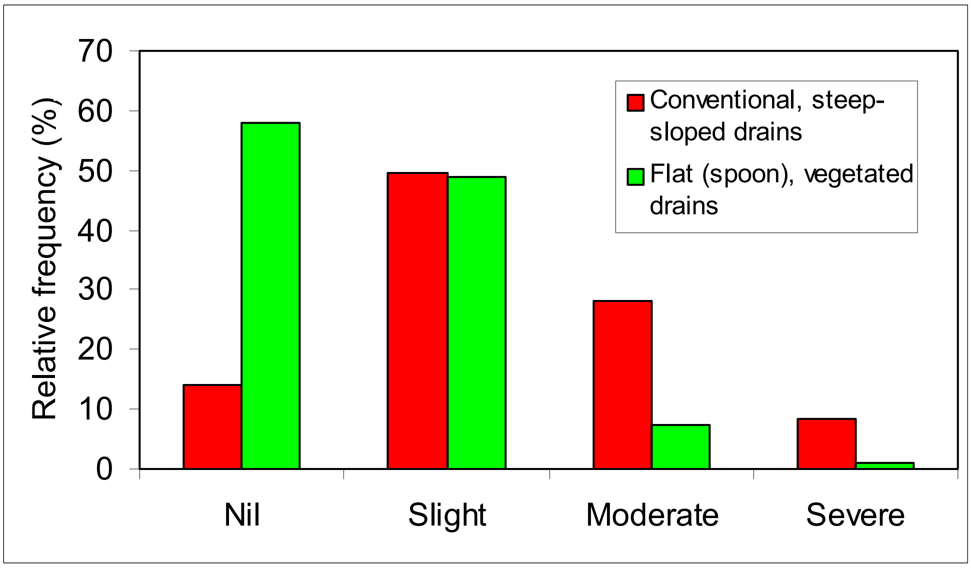

Figure 7: Incidence of drain erosion for different drain designs (data obtained from a drain survey of more than 900 drains in the Ripple Creek catchment, Herbert district; Reghenzani and Roth, 2003).

Some other noteworthy observations can be extracted from Table 3. Ratoon blocks, although protected by a trash blanket, still act as a net sediment source. This is because in reality, trash does not fully cover all parts of the paddock, in particular if disturbed by ripping or cultivation practices. At the same time, unit area erosion rates from ratoon blocks are in the same order of magnitude as the unit area soil loss from the forested uplands (~1 t/ha) and probably reflect background levels.

Taking into account the relative areal extent of each landscape element in Table 4 and using the data in Table 3, it is also possible to calculate a mean weighted unit area soil loss rate for cane land. This yields a value of 3.4 t/ha for 1999-2000 and 1.8 t/ha for 2000-2001, or an average cane land soil loss rate of 2.6

t/ha. This is slightly less than the analogous values calculated from the gauging site data in section 5.1, and this discrepancy is reflected in the comparison of the I – S term in Table 3 with the output term derived from Table 2. Note that in Table 3 in the case of fallow (~9% of the area), as we had no measured data from this cane land element, so to calculate net soil loss we made an assumption that unit area soil loss from fallow could be approximated as being the average of that measured under plant and ratoon cane.

However, the order of magnitude of the mismatch between discharge data and budget data is comparatively small. Reasons for the budget not being closed are discussed in detail by Visser (2003). In summary, a number of possible reasons for this exist. First, not all elements of cane land have been captured in the budget in Table 3. About 4% of the cultivated part of the study area has elements (other – including melons, roads, built up areas) for which we did not obtain erosion or deposition data and/or did not feel confident enough to make extrapolations from the data obtained from the other cane land elements. Exclusion of this element in the budget in Table 3 is likely to lead to an underestimation of the I – S term. Also, as shown in the detailed error and uncertainty analysis in Visser (2003), large measurement uncertainties are associated with some of the methods, in particular the sediment discharge determinations of the gauging sites, leading to possible overestimation of the output values.

In summary, on the basis of the budget data (Table 3) **and** the sediment discharge data (Table 2), we can conclude that the average export of **suspended** sediments from low-lying cane lands in the study area is likely to range between 3 and 4 t/ha and year. Given the similar soil types and rainfall conditions across much of Ripple Creek catchment, we suggest that these values are also representative of the remainder of this sub-catchment. In other areas of the Lower Herbert with similar alluvial floodplain soils, but slightly lower rainfall, we expect the average suspended sediment export to range between 2 and 3 t/ha. Whilst some uncertainty remains on the absolute sediment export value from other cane land areas, the main focus should be on the relative differences between the landscape elements, and the opportunities for further reduction of sediment export from cane land that these results provide.

5.3 Assessment of Grower Demonstration Sites

Results from the grower demonstration sites can be grouped into two categories (see Table 1). Firstly, the sites were set up to test the technical feasibility of selected management options, which were evaluated qualitatively and strongly based on grower assessments. Secondly, to evaluate the efficacy of the options in terms of reducing sediment export, we carried out a series of additional erosion pin and cross-section monitoring where appropriate, backed by visual assessment and photographic documentation.

5.3.1 Gilbert Site

Measures undertaken at this site included the installation of an innovative headland drainage system in conjunction with SRDC project BS181, and the repair of damaged headlands and spoon drains through active re-establishment of ground cover by seeding Couch grass and planting strips of Lamendra grass.

Re-establishment of ground cover in both the spoon drain and on the headland was successful, but did require a small top dressing of N fertiliser (10-20 kg/ha equivalent). Cover regained high levels within one wet season. As Figure 8 demonstrates (see columns on left side), the well-covered plots had an about 3-fold higher deposition rate, although there is some variability in this. The Lamendra grass established itself, but was slow growing and did not visibly improve sediment trapping. The grower considered this a successful trial.

5.3.2 Fortini Site

This was an interesting site, in that it was located in the Upper Stone catchment on sandy, duplex soils that were far more erodible than the clay alluvials of the floodplain. Although the rainfall in this part of the Herbert is lower, erosion, in particular gully erosion can be potentially far more severe. Two demonstration sites were established. The first site replicated the headland and spoon drain experiment carried out at the Gilbert site, in order to test its applicability on the sandier and more erodible soils of the Upper Stone area. On the second Fortini site (that was established by the grower), the focus was on managing gully erosion in a major farm drain.

Results with respect to the headland rehabilitation were not quite as clear as those obtained from the Gilbert site. Whilst re-vegetation using Couch grass, topped up with gypsum and N fertiliser (to reduce soil sodicity and to facilitate seedling establishment) led to a significant increase in ground cover, the effect on net deposition was only very small (Figure 8, right side columns). We attribute this to the dry wet season 2000-2001, resulting in only a few major runoff events in the Upper Stone area.

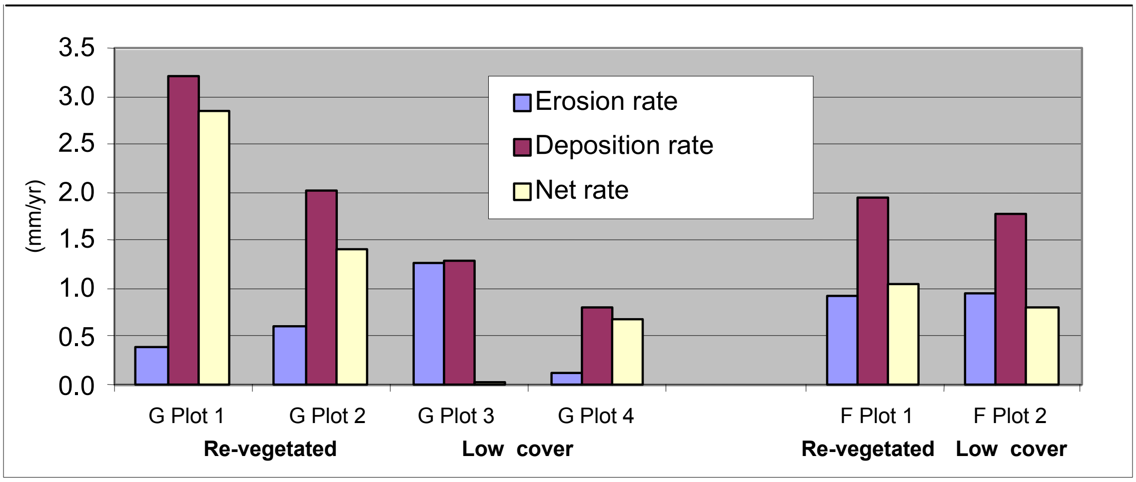

Figure 8: Results of the headland and spoon drain re-vegetation trials on the Gilbert (G) and Fortini (F) demonstration sites.

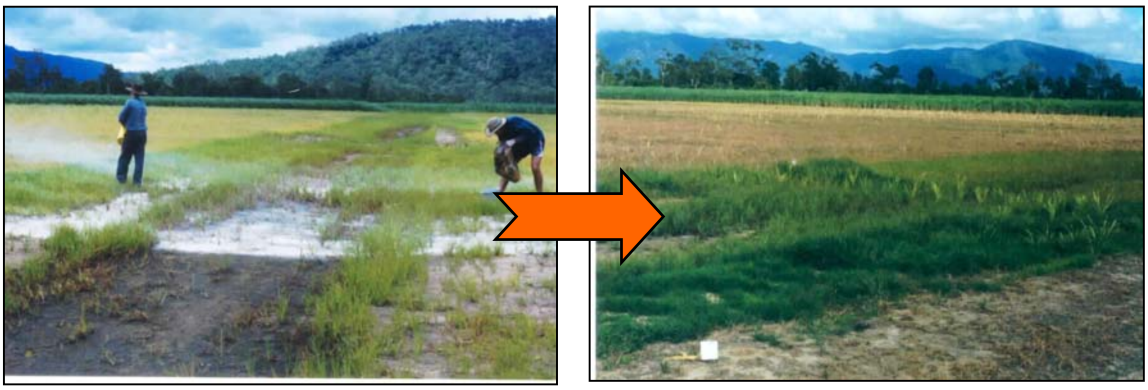

Figure 9: Revegetation of a spoon drain and adjacent headlands using Couch grass and Lamendra strips. Note application of gypsum to assist establishment on sodic soils.

The management of drain erosion was more successful. The most effective measure to control severe bank erosion and gullying in this area was found to be the establishment of drop structures, consisting in a series of rock aprons laid across the drain and covered by concrete. Within one wet season, the drain reaches between each drop structure had re-vegetated naturally and further soil incision had been successfully halted (Figure 16). Effectively, the drop structures break the drain into shorter reaches with lower slope. This slows flow velocity below the thresholds required to initiate sidewall incision. In addition, the riffle effect of the rock/concrete aprons also helps increase water quality by increasing the level of oxygen saturation of the water.

5.3.3 Jap Creek Site

This site was where the re-vegetation of a major drain was tested. The works undertaken were supported by a companion NHT-funded project that was linked to this project. The site selected on Jap Creek (a tributary of Ripple Drain) had some remnant vegetation on the south bank, but was devoid of any trees on the north bank. Both banks were steep-walled and had little or no grass cover. The northern bank had several locations were bank erosion was severe, while incidence of bank erosion on the southern bank was less. In order to replant trees and establish ground cover on the northern bank, it was necessary to first bring in a backhoe to completely reshape the bank slope, modifying it to a 45^{o} angle. The reshaped bank was then replanted with a selection of adequate tree species that were considered fast growing and shade providing (to eventually shade out the grasses, to facilitate drain bank maintenance).

Early re-vegetation was partially successful, because timing of planting coincided with the dry season, so that plants did not establish as fast as they could have if planted earlier. A major flow event occurred early into the wet season, scouring out some of the plants. Notwithstanding, the site slowly recovered and now a dense canopy is forming. The right hand image in Figure 17 portrays the site 6 months after planting.

5.4 Improved Management Guidelines

The results of the sediment budget in Table 3 give clear directions to which cane land elements need to be targeted to further minimise sediment and nutrient (i.e phosphorus) export. Management options can include the elimination of some of the sources (e.g. bank erosion in main drains, water furrows) or can comprise the enhancement of trapping efficiencies of key sinks (e.g. headlands and spoon drains), or a combination of both.

Whilst the above principles provide the necessary guidance for targeted interventions, additional information is required to develop practical and implementable solutions for each source or sink element to be targeted. This information on the practical feasibility of management options was obtained from the various grower demonstration sites (section 5.3), as well as through grower feedback during field days and workshops (held in conjunction with SRDC project BS 181). The main findings and recommendations are provided in the following sections on a cane land component-by-component basis.

5.4.1 Ratoon Fields

Although ratooned fields tend to act as a net source of sediments (Table 3), there is little scope in further reducing soil loss, as the loss values are already close to background levels. However, there are a number of recommendations that can be made to avoid increased spoil loss from ratooned paddocks:

- Maintain the trash blanket and avoid burning; burning the trash will leave the soil unprotected and more prone to erosion;
- Ensure the trash is evenly spread by the harvester during harvesting operations; and
- Avoid or minimise ripping and cultivation on ratooned blocks at the onset of the wet season, as any disturbance of the trash blanket due to tillage provides an additional source of sediments.

5.4.2 Plant Cane Fields and Fallow

As shown in Table 3 and Figure 10, plant cane fields are one of the main sources of sediments, particularly in years with an above average extent of plant cane (e.g. 1999-2000 season) due to previous crop failures and more widespread replanting.

There are a variety of management options available to reduce soil loss from plant cane. In conventional systems, we identify the following three principal strategies.

1. Where conditions allow, place a high priority on early planting, as this is seen as the most efficient means to reduce soil loss from cane blocks. Early planting will enable early canopy closure before the onset of summer storms and the wet season. This protects the soil surface and reduces surface crusting, thus maintaining higher infiltration, lower runoff and hence, less soil detachment and transport. At the same time, it allows for timely fertilisation operations, reducing the likelihood of nutrient loss in runoff. Overall, early planting also ensures the establishment of a healthier crop stand because the possibility of the stand being affected by early inundation of flooding is also reduced.

2. The establishment of cover crops during fallow periods using legumes. Providing a dense canopy cover from planted legumes (e.g. soybeans) ensures that the soil surface remains well protected throughout the fallow period. An example is given in Figure 11. This measure not only reduces soil loss, but has also been shown to be highly effective as a break to reduce the effects of long-term sugar cane monoculture on cane yields and to produce additional benefits in terms of nitrogen accumulation and yield increases following the cover crop fallow (Bell et al., 1998; Garside et al., 1996; 1997).

3. Reduction of tillage intensity by restricting intensive tillage operations (e.g. rotary hoe) to the immediate row space and leaving a rougher, cloddier surface between plant rows. Greater cloddiness and surface roughness enhances infiltration of rainfall and reduces flow velocity of runoff, thereby decreasing sediment transport capacity. Indeed, there is little agronomic justification for intensive tillage between rows, and a reduction in tillage intensity would also have benefits in terms of reduced fuel and operational costs. In practice, this measure may require alterations to existing tillage equipment (e.g. removal of rotary blades normally operating in the interrow space).

Figure 10: Plant cane field leaking sediment-laden runoff into a drain. Wider headlands and better cover in the drain than as shown here could act as a filter.

In the longer term, the introduction of controlled traffic in conjunction with permanent row beds is a feasible alternative not only to minimise soil loss, but at the same time to also change to a more productive and sustainable cane farming system (Garside, 2003). In this system, which has been shown to result in higher cane productivity, cane is direct-drilled into the stubble of a previous cover crop (e.g. soybean) that was planted into raised, permanent beds. This means that the field is covered by cane trash or cover crop stubble throughout the cropping cycle. This and the fact that soil is no longer loosened significantly during any tillage is likely to significantly reduce soil loss from this alternative production system. As yet, no actual monitoring data is available to confirm this, but based on our understanding of

Figure 11: Plant cane field well protected by an excellent cover crop of soybeans during fallow.

soil erosional processes, this is a reasonable assumption. Conversely, the long-term effect on runoff generation of controlled traffic lanes, that are highly compacted, has yet to be quantified to ensure that on balance the system proposed here does in fact provide a means to reduce the net soil loss from plant cane blocks. For further details regarding this system, which is currently under further development and testing as part of the Sugar Yield Decline Joint Venture, we refer to the work by Garside (2003).

5.4.3 Water Furrows

Water furrows are not used in all cane growing districts, but in those areas where they are a common practice to help manage inundation and waterlogging, as is the case in the Lower Herbert floodplain, they constitute a very significant source of sediments (Table 3). This is because they concentrate field runoff into deeper channels leading to an increase in flow velocity of the runoff and hence, to more erosive flow that leads to the scouring of the furrow, and a high ability to transport any sediment received from the adjacent field area (Figure 12).

Our field observations indicate that the amount of soil lost through water furrows is highly dependant on the frequency of maintenance. To retain effectiveness of the water furrows, some growers grade or reshape the furrows on an annual basis, in which case there is little protective ground cover and usually a source of readily erodible, loose soil material within the furrow itself and along the edges of the furrow.

Laser-levelling is now a common practice in the Herbert district to reduce inundation. In the course of laser-levelling most growers tend to fill in existing water furrows, which effectively eliminates furrows as a source of sediment. This would constitute the preferred means of reducing sediment from this source. However, other growers contend that furrows should be retained even in laser-levelled paddocks, claiming that the furrows will further reduce waterlogging than laser-levelling alone. Mitchell et al. (2001) have demonstrated that the efficiency of water furrows in reducing duration of waterlogging on a laser-levelled field might be fairly low, but Mitchell (2003) has also shown that cane yield is highly sensitive to even small changes in duration of waterlogging.

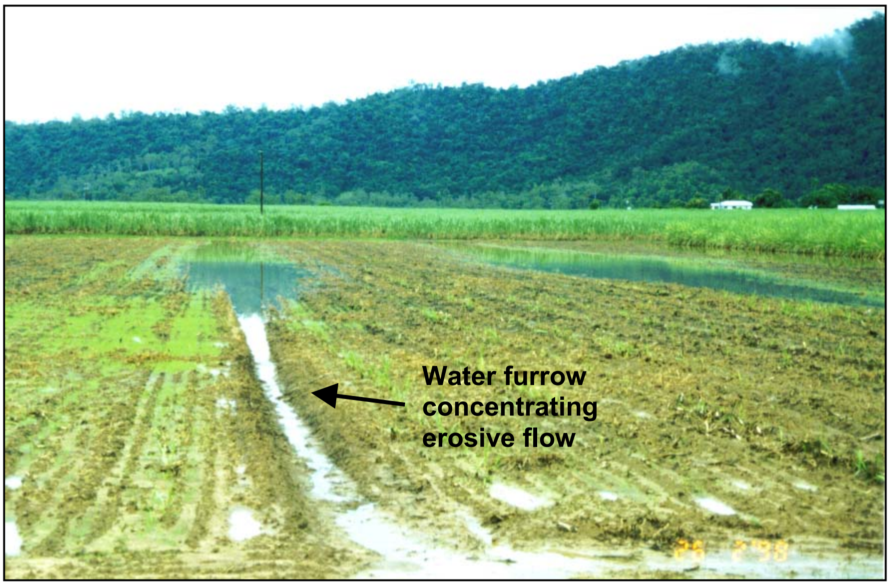

Figure 12: Water furrow concentrate flow and act as major source of sediments. Removal of water furrows in the course of laser-levelling eliminates this source.

For those growers who wish to retain water furrows, the recommendation is to reduce the frequency of grading and to tolerate some level of ground cover within the furrows (at least 65%, based on Figure 13). This will slightly reduce the drainage efficiency of the furrows, but on the basis of the more detailed data analysis provided by Visser (2003), this does leads to an overproportional decreases in soil loss from water furrows.

Soil type should also be taken in to account. Water furrows in sandier soils (e.g. on the hillslope soils around the margins of the floodplain) were observed to erode more than furrows established on the heavier alluvial floodplain soils (Visser, 2003). Hence, elimination of water furrows would be more urgent on sandier soils than on clay soils.

5.4.4 Headlands

Results in Table 3 indicate that in most cases headlands act as sediment sinks. Sediment trapping efficiency is greatly enhanced if headlands have a healthy and intact grass sward. Too frequent grading following harvest and slashing too close to the soil surface will damage the grass cover to the point that headlands will start eroding. A threshold of 80% ground cover is recommended to ensure headlands act as sediment traps and not as sediment sources. As shown in Figure 13, at cover levels below 65%, headlands will start actively eroding. An illustration of what constitutes an actively eroding headland as opposed to a well-covered headland with high trapping efficiency is provided in Figure 14.

Smoothing out of wheel ruts following harvest is best carried out by tractor pulled levelling bars and slashing height is best controlled using slashers with adjustable height wheels. Where headlands have been damaged to the point of active erosion, it may be necessary to rehabilitate the headland by seeding with Couch grass, Pangola or another suitable species, which provide good ground cover and do not increase problems of rat harborage. To ensure successful establishment of the cover plants a light top dressing of fertiliser based on a soil test is recommended. Grass establishment should take place before the onset of wet season storms.

Apart from managing ground cover, the actual design of the headland is important too. Headlands need to have a minimum width to be effective as sediment traps. Based on work done by Karrsies and Prosser (1999) and Prosser and Karssies (2001), width is dependant on slope, and recommended widths need to be 2 m wide for headland slopes of < 5%, 3 m wide for slopes 6 –7 % and 4 m wide for slopes > 7%. Furthermore, poorly designed headlands act as a barrier to drainage from the field, leading to waterlogging in the rows immediately upslope of the headland and the headland itself. This also affects accessibility of the headlands and the block. Trafficking headlands that are too wet results in ruts and damage to soil cover, increasing the need for maintenance and the likelihood of headland erosion.

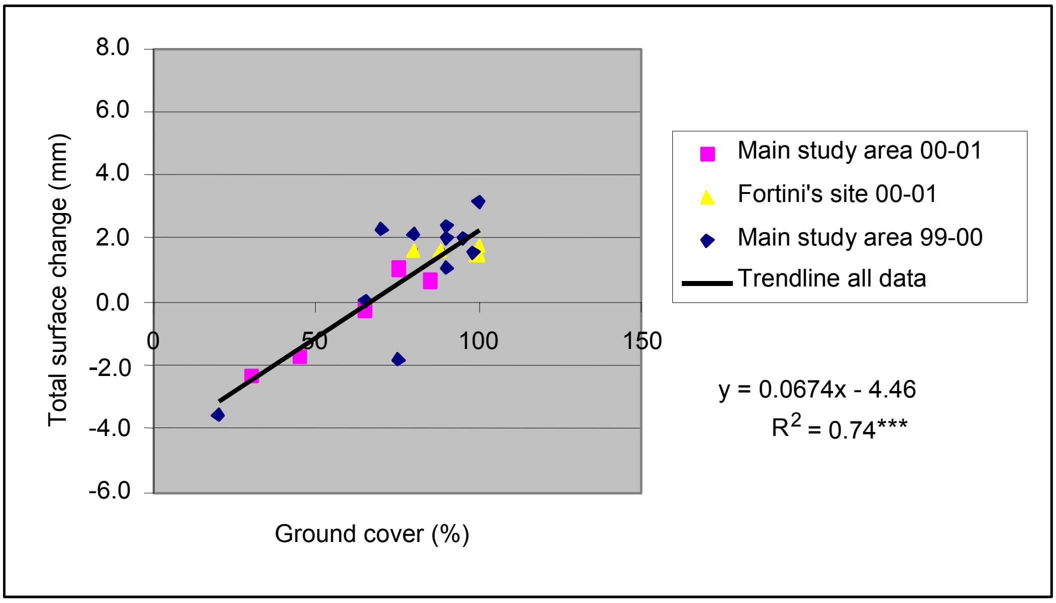

Figure 13: Relationship between amount of ground cover and functioning of headlands as source or sink of sediment.

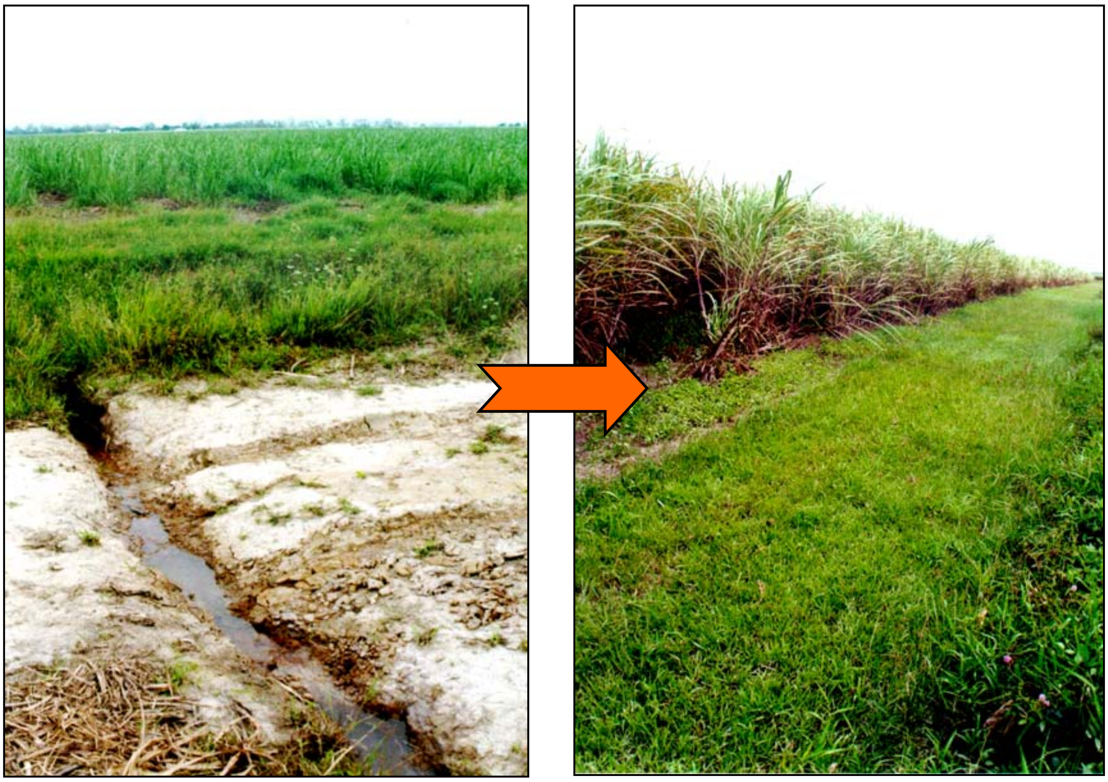

Figure 14: Actively eroding headland (left) that requires remediation to re-establish cover, contrasting with a well covered headlands acting as a trap for sediments (right).

5.4.5 Farm Drains

Farm drains are those drains that are the primary conduits of runoff collected from fields. They can be very diverse in size and design and are managed by growers. They feed into the main drains of the drainage networks that are usually maintained by a drainage board or a water board.

The analysis of the extensive drain survey conducted in Ripple Creek in the Herbert district shows a clear trend of increased drain erosion associated with older, traditional steep walled drains (Figure 7). Conversely, flat, grass-covered spoon drains erode less, are easier to maintain and if well covered (> 80 % cover) function as sediment sinks (Figure 13; see also Table 3). Where ever possible, minor farm drains need to be flat and well covered with grass to enhance their ability to act as sediment traps, much like extended filter strips and headlands. Indeed, in most cases farm drains are now established as shallow spoon drains.

In those cases where spoon drains are not an option, it is essential that the drain banks be shaped to an angle of about 45 degrees or less, to enable ground cover to establish on the drain wall. Pangola grass (*Digitaria decumbens*) has proved particularly suitable for this task (Figure 15). It is easy to establish, low maintenance and does not impede water flow. The grass should not be slashed or removed during drain cleaning in order to retain protection against drain bank erosion. Cleaning operations should be constrained to the base of the drain and solely to remove deposits, preferably leaving the grassed drain banks untouched.

Figure 15: Example of a well-grassed drain bank with Pangola grass established by growers in the Herbert district.

An additional enhancement for sediment trapping is the establishment of tussock grass strips along the edge of the drain. Where such grass filter strips along drains have been established using species like Vetiver grass, farmers have found that these strips protect drains from erosion as well as filtering sediments leaving cane blocks.

Another problem that can be encountered when designing farm drains is that the slope of the farm is too steep to allow for spoon drains to be established safely. Examples of this occur on steeper, sandier and often dispersive soils on foot slopes of hills and mountains surrounding the actual floodplains or river flats. In this case, drains can be broken up into flatter sections separated by drop structures that mitigate flow energy and avoid gullying or incision of the drain.

Figure 16 illustrates an example of successful drop structure control measures, carried out by a grower on a very erodible soil in the Stone River area of the Herbert district. Drop structures can be constructed using concrete aprons on more dispersive and vulnerable soils, while rock piling might be sufficient on less vulnerable soils. In all cases, fringes around the drop structures need to be well grassed to avoid new incision at the edges of the structures. An environmental benefit of drop structures such as those suggested above is that they enhance aeration of drain waters through their riffle effect. Water in cane land drains has shown to be frequently oxygen deficient and lack of oxygen has been recognised as the main problem for fish and other aquatic species (Pearson et al., 2003).

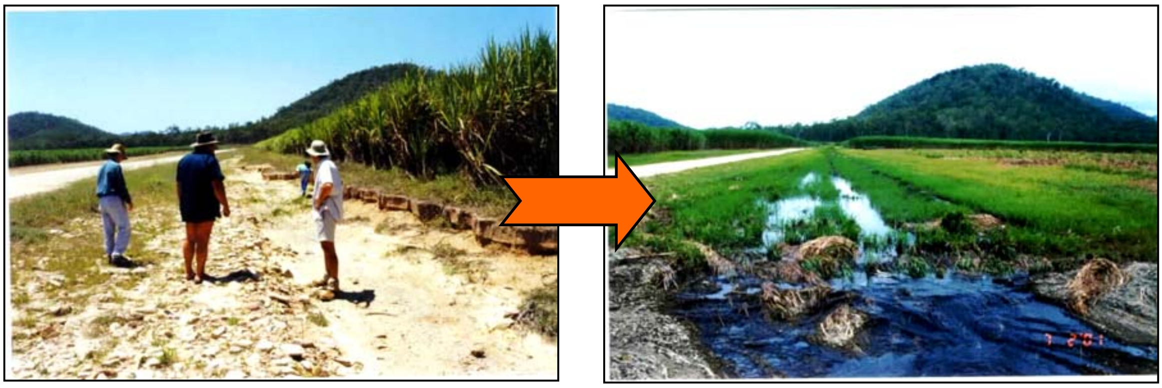

Figure 16: An example of a successful series of drop structures established on a farm drain that was too steep and cutting into dispersive soils, resulting in high drain erosion rates. Rock piling and concreting at regular intervals were sufficient to slow flow and stabilise the drain.

5.4.6 Main Drains

Main drains are those drains that link major farm drains and provide the main conduit of drain waters out of a particular drainage network or sub-catchment. They are usually managed by drainage or water boards. As shown in Table 3 for Ripple Drain (the main drain in the Ripple Creek sub-catchment, Lower Herbert), they can vary significantly in their propensity to act as net sink of sediments, depending on the magnitude and balance of bank erosion and drain bed deposition.

In general terms, the same management principles apply as for major farm drains, as discussed in the preceding section. However, given their dimensions, they offer the additional opportunity to improve water quality and aquatic habitat conditions by re-establishing riparian tree vegetation. Given that these drains are larger, flow energy is also greater. Using trees as bank stabilisation therefore constitutes a better alternative to stabilising bank erosion than grass cover, provided that the correct tree species are selected and that the trees are planted in sufficiently high density (Figure 17). High tree density is required to form a dense root mat along the entirety of the drain bank to avoid preferential scouring of the drain bank, and also to ensure that a dense tree canopy will provide a high level of shade. A high level of shade is required to inhibit grass growth beneath the trees in order to minimis rat harbourage. Shading of the drain can also significantly decreased the incidence of light dependant aquatic weeds such as Para grass and Hymenachne. Elimination of such weeds by shade reduces drain maintenance costs, but more importantly, improves the oxygen status of the drain water. Shade also reduces water temperature, which further improves oxygen status. Thus, the combined effects of lower water temperature and elimination of weeds lead to a significant enhancement of drain water quality, making the drain a more attractive fish habitat (Pearson et al., 2003).

Other opportunities to enhance the environmental performance of big drains include the formation of artificial wetlands and the introduction of silt traps. Examples for improving drains in the Ripple Creek area and some design principles are provided by Butler and Burrows in Roth et al. (2001). The system established by Ross Digman in Tully provides an additional example of how drains can be made into something more than the mere conduits of excess water.

Figure 17: Examples of effective control of drain erosion. Left example: right bank protected by a dense cover of grass and growing trees that will eventually shade out the grass and reduce rat harbourage problems; left bank sprayed and with little cover – not recommended. Right example: showing a reshaped drain bank prior to revegetation with species selected to maximise future shade and of moderate height to avoid branching and interference with harvester operations.

Drain re-vegetation with trees, which in many cases will require earthworks to reshape the drain wall, is a costly measure and usually a complete re-vegetation of drains will require funds beyond the means of individual farmers or even drainage boards. In this case, re-vegetation needs to be highly targeted and it is recommended to conduct a drain survey to identify the hotspot drain sections most in need of rehabilitation. Figure 18 provides an example of how the drain survey carried out in Ripple Creek sub-catchment can be used to identify the hotspots within a drainage board area. It shows that probably only about 20% of the drainage network needs to be targeted in the case of Ripple Creek, starting from the hotspot section nearest to the mouth of Ripple Creek and then gradually working upstream.

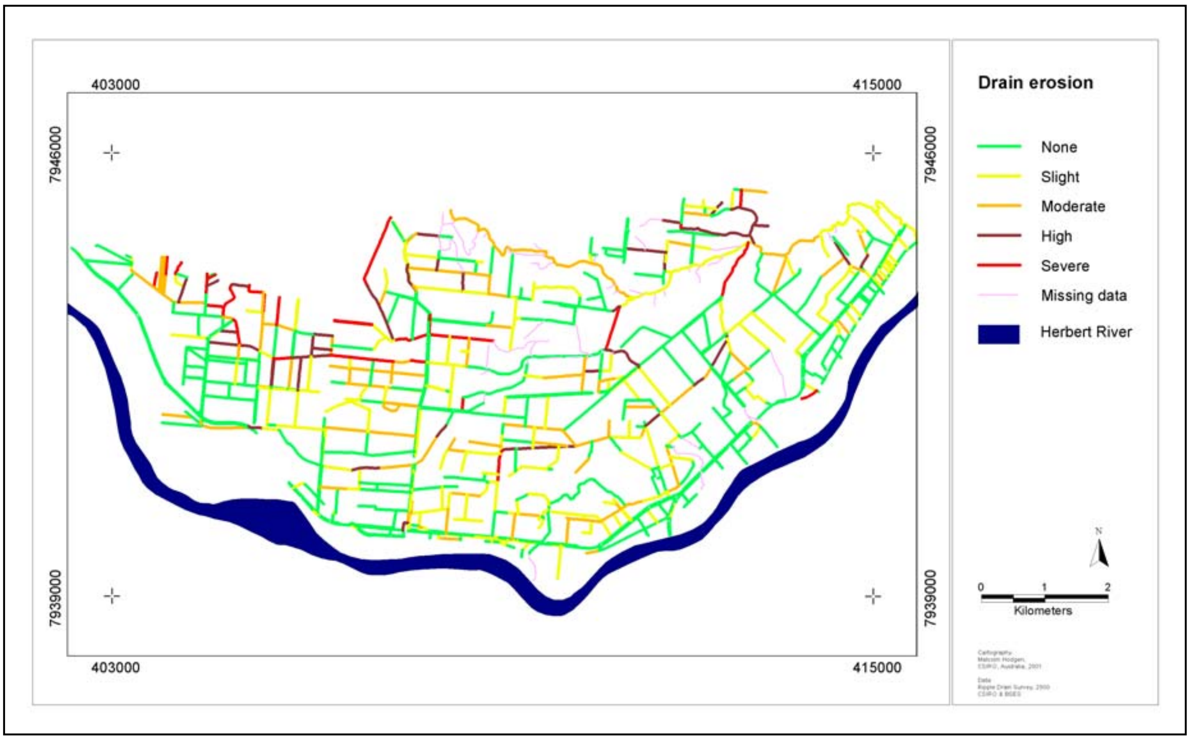

Figure 18: Results of drain erosion survey carried out in Ripple Creek sub-catchment, Herbert district, indicating drain section most in need of drain bank re-vegetation.

5.5 Using the Sediment Budget to Develop Water Quality Targets

In this section we integrate the information provided in the preceding sections into frameworks that allow for the results of this project to be used in different levels of future water quality target setting exercises. Setting of water quality targets will become mandatory as Regional NRM Bodies being constituted as part of the National Action Plan for Salinity and Water Quality and NHT2 proceed with the development of accredited Regional NRM Plans and also to meet the requirements of the future Reef Protection Plan.

In the first instance, we propose a qualitative framework (Figure 19) based on mapping different cane component management regimes against erosion or deposition classes; the ranking of these management regimes is derived from the sediment budget in Table 3. In this framework, each management regime can be interpreted to be a specific management target, and the aim would be to move from current management regimes to higher management regimes in order to move from net erosion to conditions of net deposition. This framework is considered to be more widely applicable outside the study area of this project, as it generalises the actual measured erosion and deposition rates into five broader erosion and deposition classes. Areas where this framework is likely to hold include most of the Lower Herbert floodplain (i.e excluding the steeper, hillslope soils), the Mackay district (floodplain only) and most of the low-lying cane lands of the Wet Tropics coast.

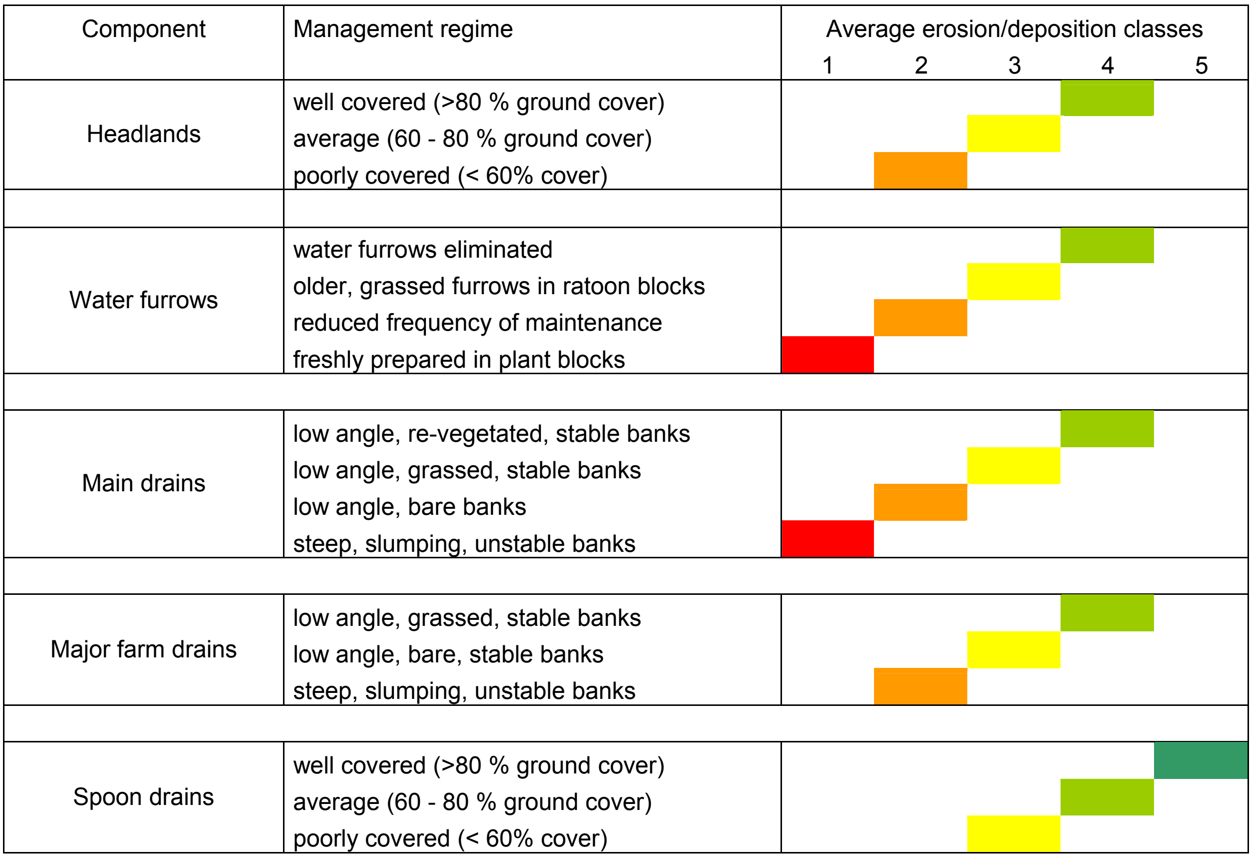

Figure 19: Effect of management on erosion/deposition of sediment for different cane land components. (1/red = high net erosion; 2/orange = moderate net erosion; 3/yellow = low to negligible erosion or deposition; 4/light green = moderate net deposition; 5/dark green = high net deposition).

In Ripple Creek sub-catchment and for the remainder of the Lower Herbert floodplain, the sediment budget in Table 3 lends itself to be used in a spreadsheet to quantify the relative benefits of different management strategies on the reduction of sediment export. This is demonstrated in Table 5, where we present the output of such a spreadsheet for a range of different management scenarios. The left hand column in Table 5 lists the average sediment budget figures taken from Table 3 and sets the total net sediment output (Input – Storage) of –963 t at 100%. In the five columns to the right we sequentially evaluate the effect of the various management options in their effectiveness in reducing sediment export for the conditions prevailing in Ripple Creek sub-catchment. Changes to erosion and deposition rates as a result of assumed changes to management of cane land components are highlighted in light green in Table 5. At total of five exemplary scenarios were defined and evaluated:

Scenario 1: Headland management is improved by all growers in the Ripple Creek area by maintaining better ground cover (reduced frequency of slashing) and repairing damaged headlands; we assume this leads to a decrease in headland erosion by 33% and in increase in headland trapping efficiency of 20%, increasing unit area net deposition rate from 5 t/ha to 12 t/ha;

Scenario 2: The area of paddocks with water furrows is halved by laser-levelling of fields and elimination of water furrows; this reduces the total sediment loss from –475 t to –212 t, which is slightly offset by a proportional increase in net erosion from ratoon and plant cane fields (due to water furrow area becoming additional paddock area);

Scenario 3: In this case the assumption is made that growers and the drainage board decide to address bank erosion of main drains and major farm drains by reshaping and revegetating main drains and by establishing protective ground cover on banks of farm drains, respectively; we assume that this measure reduces erosion from the main drain (Ripple Drain) by 25% and from farm drains by 50%, leading to an increase in net deposition from 40 to 85 t and 22 to 76 t, respectively;

Scenario 4: Combines scenario 1 and scenario 2; and

Scenario 5: Combines scenarios 1, 2 and 3.

Table 5: Effectiveness of erosion mitigation measures on relative reduction of total sediment export.

Sources	Current (Table 3)		Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	t/ha	t	t/ha	t	t/ha	t	t/ha	t	t/ha	t	t/ha	t
Headlands erosion	12	271	8	179	12	271	12	271	8	179	8	179
Headlands deposition	17	367	20	441	17	367	17	367	20	441	20	441
Headlands net	**5**	**105**	**12**	**278**	**5**	**105**	**5**	**105**	**12**	**278**	**12**	**278**
Water furrows erosion	42	960	42	960	42	480	42	960	42	480	42	480
Water furrows deposition	23	517	23	517	23	258	23	517	23	258	23	258
Water furrows net	**-19**	**-425**	**-19**	**-425**	**-19**	**-212**	**-19**	**-425**	**-19**	**-212**	**-19**	**-212**
Ripple Drain erosion	86	187	86	187	86	187	64	140	86	187	64	140
Ripple Drain deposition	104	227	104	227	104	227	104	227	104	227	104	227
Ripple Drain net	**19**	**39**	**19**	**39**	**19**	**39**	**40**	**85**	**19**	**39**	**40**	**85**
Major drain erosion	60	207	60	207	60	207	30	104	60	207	30	104
Major drain deposition	52	178	52	178	52	178	52	178	52	178	52	178
Major drain net	**-9**	**-29**	**-9**	**-29**	**-9**	**-29**	**22**	**76**	**-9**	**-29**	**22**	**76**
Minor drain erosion	21	43	21	43	21	43	21	43	21	43	21	43
Minor drain deposition	55	117	55	117	55	117	55	117	55	117	55	117
Minor drain net	**35**	**74**	**35**	**74**	**35**	**74**	**35**	**74**	**35**	**74**	**35**	**74**
Ratoon fields	**-1.1**	**-136**	**-1.1**	**-136**	**-1.1**	**-145**	**-1.1**	**-136**	**-1.1**	**-145**	**-1.1**	**-145**
Plant cane fields	**-3.8**	**-376**	**-3.8**	**-376**	**-3.8**	**-386**	**-3.8**	**-376**	**-3.8**	**-386**	**-3.8**	**-386**
Fallow	**-2.4**	**-74**	**-2.4**	**-74**	**-2.4**	**-74**	**-2.4**	**-74**	**-2.4**	**-74**	**-2.4**	**-74**
Forested uplands	**-1.0**	**-216**	**-1.0**	**-216**	**-1.0**	**-216**	**-1.0**	**-216**	**-1.0**	**-216**	**-1.0**	**-216**
Total (Input - Storage)		-1037		-865		-844		-887		-671		-520
Relative reduction (%)		**100**		**83**		**81**		**86**		**65**		**50**

As shown in the bottom row of Table 5, even simple measures like improved management of headlands or the gradual elimination of water furrows following laser-levelling (which is a widely adopted practice to enhance surface drainage in the Lower Herbert) provide scope of reducing sediment export by as much as 20%. Repairing eroding drain banks is an equally effective measure in the scenarios tested here (reduction of sediment export by about 16%), but is likely to be far more expensive. Combining improved headland management and elimination of water furrows (scenario 3) has the potential to reduce sediment export from Ripple Creek sub-catchment by about 40%, and if combined with drain bank stabilisation, the level of reduction falls below 50%. This would constitute a significant reduction, and lies within the order of magnitude of targets proposed in the GBRMPA Water Quality Plan of 2001 (Brodie et al., 2001). Hence, achieving such targets can be shown to be quite feasible. It is also worth noting that the scenarios tested here do not change the way growers currently manage ratoon and plant cane paddocks. Thus, there is even more scope for reduction of sediment export once growers start adopting the improved farming systems being proposed by the Yield Decline Joint Venture (Garside, 2003).

This little exercise clearly demonstrates the value of developing sediment budgets as a tool to better understand the key soil erosion and sediment transport processes and to place them into a landscape context. The spreadsheet behind Table 5 is easily used in a workshop or shed meeting environment and would allow growers to explore for themselves what the best options would be. It also demonstrates that significant initial improvements can be achieved with relatively low demands on grower resources.

Whilst the scope to reduce sediment export on the basis of simple, targeted management actions that go beyond the management of paddocks and take into account all elements of low-lying cane lands is very encouraging, the question arises how effective this may be in reducing nutrient exports. Unfortunately, this project was not resourced to allow for the determination of robust N and P loads leaving the study area. As an alternative, we evaluated the potential of nutrient export reduction as a result of lower sediment export rates by relating sediment concentration to nutrient concentrations using data obtained earlier in the Herbert and collated by Bramley and Muller (1999).

For the purposes of this evaluation, we selected the Gollogly and Covell Rd sites from the Bramley and Muller dataset, these being sampling sites on Ripple Drain discharging from catchment areas with a similar ratio of forested : cane land as for the study area (40 : 60). We plotted total N and P, particulate N and P and dissolved N and P against total suspended solids, respectively. These plots are presented in Figure 20. It is evident from these plots that most of the N in drain waters is in dissolved form (~85%; mainly as NO_3, NH_4 and soluble organic forms) and that the relationship between dissolved N in drain waters and suspended sediments is very poor. On average 31% of the total N was in NO_3 + NH_4, but with a very wide range varying between 3 and 79% (data not shown). This is to be expected, and reflects the fact that N concentrations in drain waters are largely determined by the amount of soluble N supplied via fertilisers, its form and method of application and timing of fertiliser application in relation to incidence of rainfall. The coefficient of determination between concentration of suspended sediments and particulate N is better and statistically significant, but is still characterised by substantial scatter. Overall, reducing sediment loads is therefore only going to partially reduce the export of dissolved N. Other management practices will have to be introduced to achieve that, but a discussion of N management is beyond the scope of this report.

Conversely, concentrations of P, irrespective of its form, are far more closely related to the concentration of suspended sediments. The best relationship was found between particulate P and suspended sediments. Based on the data shown in Figure 20, about 63% of total P is lost in dissolved form, either as PO_4 or dissolved organic fractions, which is higher than expected. On average, about 20% of total P is lost as PO_4, but values range widely between 4 and 54%. These results clearly suggest that any reduction in sediment export is also going to substantially reduce the export of P. Hence, the management options to reduce sediment export presented earlier are directly applicable to the reduction of P losses to waters draining cane lands. In addition, Bramley et al. (2003) have developed refined P fertiliser management guidelines for the Herbert district based on a better differentiation of soil P as the basis for more refined P application rates. A general lowering of P concentrations in soils of the Herbert following reduced P fertilisation rates as proposed by Bramley et al. (2003) will further reduce P export by lowering the regression coefficients of the P vs. TSS curves shown in Figure 20.

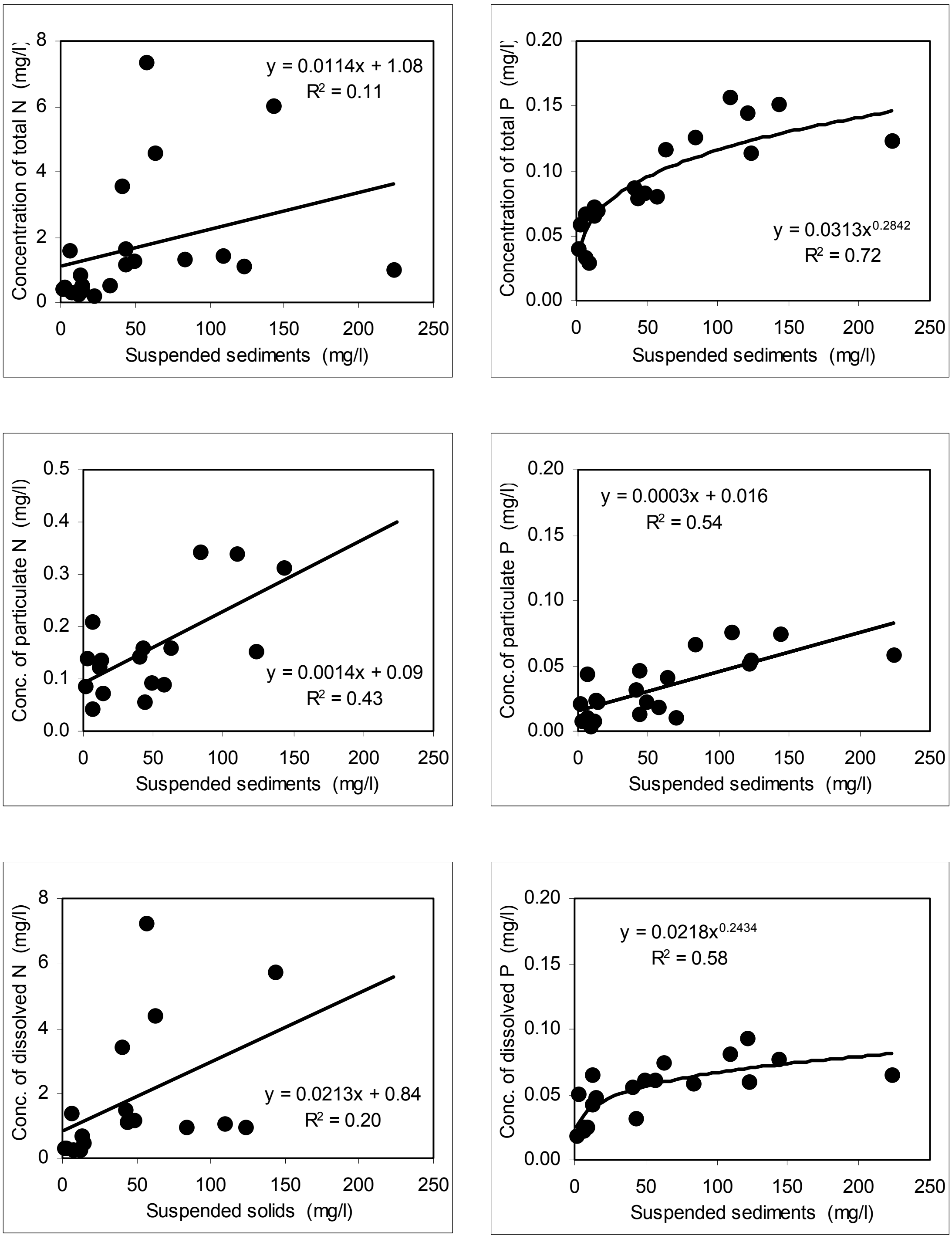

Figure 20: Relationship between suspended solids and total N and P, particulate N and P and dissolved N and P, for samples collected in Ripple Creek sub-catchment, Lower Herbert (data taken from Bramley and Muller, 1999)

6. Outputs

The main deliverable of this project is the PhD Thesis submitted by Fleur Visser. Hardcopies are provided together with this report, and a PDF version is included on the CD in the back sleeve of this report. Outputs generated in conjunction with the thesis are:

- Baseline data on current soil erosion and deposition rates of cane land elements, and on sediment discharge from cane land representative of low-lying cane lands in the Herbert district;

- Documented methodologies to monitor soil erosion and deposition in cane lands, ranging from sophisticated, automated sampling equipment to simple and cost effective methods suitable for use by catchment groups, drainage boards and individual growers;

- A sediment budget quantifying the key sources and sinks of sediments and the main pathways of sediment transport; and

- An analysis of uncertainty to underpin the sediment budget and to enable a judgement on reliability of different monitoring methods for future applications.

In terms of dissemination of project results, the main output we produced is a suite of management recommendations and guidelines to reduce sediment export from low-lying cane lands. These recommendations and guidelines are contained in various forms in the following deliverables:

- A report on recommendations to enhance the environmental performance of drainage improvement works proposed under the Sugar Industry Infrastructure Package for the Lower Herbert, by incorporating the guidelines into an Integrated Drainage Plan for Ripple Creek sub-catchment (Roth et al., 2001);

- A draft manual for the surface drainage of low-lying cane lands, being finalised as part of BS181 (Reghenzani and Roth, 2003);

- A PowerPoint presentation routinely used in workshops and grower meetings to propagate the findings of the project; and

- A CSIRO Land and Water Technical Report summarising the results of Fleur Visser's PhD Thesis in a grower friendly way and that will be made available shortly on the CSIRO Land and Water website (Roth and Visser, 2003).

These deliverables and all other relevant publications listed in section 10 are contained on a CD provided in the back sleeve of this report.

Timetable for the finalisation of the Best Practice Surface Drainage Manual is as follows:

- 15th January 2004 – provision of revised draft manual to the members of the Herbert CPI Drainage R&D Focus Group for final comment;
- Meeting on the 6th February of the Focus Group to sign off on manual;
- 20th February - final feedback incorporated;
- 15th March - layout completed;
- 31st March – printing completed; and
- 15th April – launch of manual.

7. Outcomes

The main scientific outcome of this project is that we now have a very good understanding of key erosion and deposition processes taking place in low-lying cane lands. To our knowledge, the sediment budget developed as part of this project represents the first sediment budget produced for cane lands globally. It is also one of a few to deal with the scientifically very challenging problem of defining a sediment budget for a floodplain with flow dependant catchment boundaries and complicated by flow reversal problems.

This enhanced scientific understanding provides a firm basis for the industry to further improve its environmental performance with respect to water quality. There are a number of examples that illustrate that this is now occurring as a result of the project. Growers that collaborated with the project or that have been exposed to the project findings have now been able to better assess the options they have to reduce sediment export from their farms. As a result some growers associated more closely with the project were early adopters of some aspects of improved cane land management, in particular the improved management of headlands (less frequent slashing; slasher raised slightly higher above ground) and the reduced level of water furrow maintenance (tolerating grass cover in furrows; reducing frequency of re-grading). More recently, growers in the Ripple Creek sub-catchment have committed themselves to the implementation of improved headland and drain management regimes as an in-kind contribution to the Sugar Industry Infrastructure Package (SIIP) for the improving drainage management in parts of the Lower Herbert. In summary, the most visible sign of a shift in thinking is the recognition that cane growers manage a range of landscape elements constituting cane land as opposed to mere cane fields or blocks.

Beyond the Herbert district, there has been a strong demand for information on monitoring methods and guidelines to reduce sediment export, notably the Tully, Mulgrave and Mossman districts. This information has been provided by way of presentations to grower groups and the SIIP related report (Roth et al., 2001), and a number of catchment coordinators have already obtained copies of Visser's PhD Thesis. It is very likely that the management guidelines proposed here will be accepted as constituting 'Best Management Practice' and incorporated into the Douglas Shire Water Quality Improvement Plan (WQIP) currently underway as one of the Reef Protection Plan's 'no regrets' actions. This project is seen as a pilot for the Wet Tropics coastal cane production districts, and if successful, might serve as a blueprint for the development of WQIPs for other coastal cane catchments as well.

The above demonstrates that the longer term outcome of this project will be a gradual reduction of current levels of sediment and P export, leading to an overall reduction of cane production impacts on waterways draining cane lands at least in some districts. However, the full potential of these beneficial outcomes has yet to be capitalised on by the industry. Given that some of the measures proposed are readily implementable and low cost to growers, there is an opportunity to quickly demonstrate some more successes and thus help the industry improve public perception of its environmental performance. In the mid term, this could be further supported by the incorporation of the guidelines into the Industry Code of Practice, future updates of COMPASS or inclusion into industry EMS.

Ultimately, through the project results, the industry is now far better informed than it was before and in a good position to constructively engage in the process of implementing realistic and achievable water quality improvement targets.

8. Future Research Needs

Based on the results obtained in this project and taking into consideration further environmental requirements the industry is likely to have to meet in relation to water quality, we identify five topics in need of further research. These are listed below, in increasing order of priority.

Additional baseline or calibration data

The data presented in Table 3 represents a benchmark for low-lying cane lands and can be directly used for target setting purposes in the Lower Herbert as illustrated in Table 5. However, similar data is lacking for all other cane districts. It is likely that for some districts that are very different to the study area in terms of soils and topography (e.g. the Childers, Johnstone and Atherton Tableland regions) erosion and deposition rates of individual cane land elements (indeed, some may be absent) will diverge significantly from the data shown in Table 3. This not only changes the overall values for sediment export, but also is likely to change the relative significance of each landscape element. This potentially impairs the proposed approach of targeting land management at the key sediment sources and sinks in those districts.

Selection of appropriate drain revegetation species

One constraint to a more widespread uptake of drain re-vegetation stated by growers is the concern that provision of ground cover using grasses might lead to an increase of cane rat damage because such cover may provide additional opportunities for rat harbourage. Growers identified *Pangola* grass as a suitable grass to avoid build-up of rat numbers, and it was on that basis that it is being recommended in this report. However, so far no systematic analysis of which species are the most appropriate for the establishment of ground cover on drain banks has yet been carried out. This is equally true for the selection of tree species, although some anecdotal information exists. With respect to trees and shrubs, species will need to be selected to meet a number of criteria to be accepted by growers, including quick canopy growth to shade out weeds, potential value as timber species, high survival rate of seedlings and a reduced propensity to form low, lateral branches to avoid interference with farm machinery.

Assessment of the potential of improved farming systems to reduce sediment and nutrient export

The guidelines proposed here focus mainly on cane land elements other than cane fields, although some recommendations are also made with respect to plant cane fields in section 5.3.2. The development of more sustainable cane farming systems being carried out under the auspices of the Sugar Yield Decline Joint Venture (SYDJV) offer additional potential opportunities to minimise sediment and nutrient discharge from plant cane fields. Conversely, higher compaction likely to develop in the controlled traffic lanes propagated as part of these systems might also translate into higher risk of runoff. At present, no assessment of these new systems is being undertaken with respect to their potential benefits (or risks) to the minimisation of sediment and nutrient export. Existing SYDJV trials could be fairly easily supplemented with appropriate monitoring equipment to fill this gap cost effectively.

Management of N export from cane lands

One of the key environmental challenges facing the industry is minimising N losses from cane land. As clearly shown in Figure 19, discharge of nitrogen from cane lands is not well related to sediment export and hence, reduction of sediment export will only be partially successful in minimising N losses in runoff. At the same time, nitrogen is seen as one of the critical factors impacting on riverine and marine water quality. However, no robust N balances that simultaneously quantify all N fluxes have yet been established for cane land, in particular that provide reliable measures of N losses in runoff. This represents a major gap in terms of our ability to assess the relative significance of runoff versus other loss pathways (denitrification, volatilisation, leaching) and spatial and temporal variations in the relative significance of the individual loss pathways. This means that an effective targeting of appropriate management options is currently not possible. Similarly, there is little quantitative assessment of the most effective fertilisation regime in relation to risk of N in runoff. This means it will be difficult to develop robust, quantitative N reduction targets for cane lands that are clearly linked between on-ground action and catchment response.

Target setting and trade-off analysis tools linking paddock scale action to catchment response

Increasingly, catchment management groups and Regional NRM Bodies will find themselves confronted with the need to define a range of aspirational and management targets to achieve better water quality. It is likely that Water Quality Improvement Plans will become one mechanism for achieving such outcomes in many of the coastal catchments adjacent to the high-risk areas of the Great Barrier Reef World Heritage Area. In this report we demonstrate one way of addressing the development of sediment and P reduction targets. However, there is still a need to develop improved modelling tools that allow for an assessment of the benefit of local scale management actions (paddock, farm) at a broader sub-catchment or catchment response level (as local targets have to be set in the context of end-of-valley water quality targets). Currently, no suite of modelling tools allows doing this for cane lands, although a number of model components exist that could be coupled into such a modelling framework, in particular for N. In addition, Regional NRM Bodies will have to prioritise investments into different interventions at a catchment level, possibly having to trade-off between different land uses or industries. Currently, no quantitative tools exist that allow for an economically and environmentally based trade-off analysis for different land use or intervention scenarios.

An opportunity exists for such tools to be developed with a comparatively low R&D investment by building on the substantial body of work already carried out in the Herbert district and in Ripple Creek sub-catchment in particular. Through BS181 we have already set up MIKE 11 for Ripple Creek sub-catchment. MIKE 11 is a fully deterministic surface flow routing model that allows for instantaneous flow and discharge to be determined at any point ion the drain and waterway network. This could be coupled to the sediment budget developed in CLW007 to model sediment discharge through the sub-catchment, while data obtained through JCU016 would assist in calibrating the model for N discharge. When coupled to a catchment scale model such as SedNet, this modelling framework would allow for various N management and cane land management scenarios to be tested with respect to their effectiveness in reducing catchment level sediment and nutrient discharge at a whole-of-catchment scale. A detailed SedNet model for the Herbert catchment is currently being developed for the Herbert Catchment Management Group. Key spatial data sets required for catchment-wide scenario analysis are available in the Herbert Resource Information Centre.

Linkages to the R&D gaps discussed above (assessing new farming systems; N balances) would ensure a systems approach is taken that provides a better process understanding to underpin the development of refined, quantitative decision making tools and target setting protocols. Such tools will be essential to assist the cane industry in its choices to improve its environmental performance against the backdrop of selecting financially feasible management interventions at farm and at landscape level.

9. Recommendations

Improved management recommendations and guidelines are provided in sections 5.3 and 5.4 of this report. In this section we make additional recommendations in relation to the further dissemination of project results and to address priority R&D gaps.

Recommendation 1

In addition to the integration of the guidelines into the surface drainage manual being finalised as part of BS181, we recommend that this report be made available to the general public, after the following steps are undertaken:

- Modification of the report to make it more grower friendly (elimination of sections required for the purpose of reporting to SRDC; simplification of the language);
- Peer review by two independent scientists;
- Publication of the report on the Internet as a downloadable PDF file on CSIRO Land and Water's website or any other appropriate website; and
- Targeted mail out of printed versions of the document to coordinators of catchment management groups in coastal areas dominated by cane production, drainage and water board managers, chairs of landcare groups, regional support officers, regional technical staff of relevant agencies (EPA, NR&M, DPI, GBRMPA) and regional offices of CANEGROWERS, BSES and mills.

Recommendation 2

We recommend discussions be initiated between SRDC, the project team, BSES and CANEGROWERS on how to best incorporate the management guidelines into future updates of the Industry Code of Practice, COMPASS and future industry-led EMS or grower accreditation schemes.

Recommendation 3

We recommend that SRDC consider the commissioning of a scoping study to assess the feasibility of integrating existing information in the Herbert obtained from SRDC projects BS181, CLW007 and JC016, Sugar CRC projects 1.1.2 and 2.3.5.1 and the Herbert SedNet model into a broader modelling framework to develop robust water quality target setting and trade-off analysis tools for the Herbert and similar cane production districts.

10. List of Publications

Post, D. A, A.E. Henderson, L.K. Stewart, C.H. Roth, and J. Reghenzani, 2001: Simulating the impact of changes in drainage design on hydrologic response using a 1-dimensional flow-routing model. Proc. MODSIM 2001 Intl. Congress on Modelling and Simulation, 10-13 Dec. Canberra, Vol.1, 71-76.

Post, D. A, A.E. Henderson, L.K. Stewart, C.H. Roth, and J. Reghenzani, 2002: Optimising drainage from sugar cane fields using a one-dimensional flow-routing model: A case study from Ripple Creek, North Queensland. J. Envrion. Modelling and Software. *In print.*

Reghenzani, J. and C.H. Roth, 2003: Surface drainage of low-lying sugarcane lands. A manual for canegrowers. *In preparation.*

Reghenzani, J., C.H. Roth, B. Simpson, D. Smith and F. Visser, 2003: Managing losses from agriculture on floodplain environments. Proceedings Nat. Conf. on Sustaining Aquatic Environments. Townsville, Nov. 2001, *accepted.*

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13. List of Materials Contained in Appended CD

Documents

Reghenzani, J., C.H. Roth, B. Simpson, D. Smith and F. Visser, 2003: Managing losses from agriculture on floodplain environments. Proceedings Nat. Conf. on Sustaining Aquatic Environments. Townsville, Nov. 2001. [Copy of manuscript submitted].

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Posters

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Presentations

PowerPoint presentation by C.H. Roth and J. Reghenzani:Managing sinks and sources of sediments to reduce the impact of cane farming on the environment
- lessons from the Herbert -