Quantifying sediment sources in lowlying sugarcane land: a sediment budget approach

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Abstract The flood plain of the Herbert River basin is predominantly used for sugarcane cultivation. Although flood plains are generally considered depositional areas, high sediment concentrations have been observed in the water draining from cane land. Erosion control measures have reduced erosion from cane fields, but other landscape elements (e.g. drains) could still be important sediment sources. For this study the total sediment output from a cane area was gauged and the contribution of a range of landscape elements was quantified with traditional erosion measurement methods. A sediment budget is used to both present and check the measurement results. The study indicates that this tropical flood plain area is a net source of sediment. Sediment loss from the cultivated cane land was 3.9 t ha^{-1} between 1 December 1999 and 31 May 2000.

Key words Herbert River; Australia; flood plain; humid tropics; sediment budget; erosion measurements; sediment sources; sediment storage

INTRODUCTION

Intensification of agriculture in Australia since European settlement has caused an increase in sediment export from Australian river basins. The increased sediment load has a potentially harmful impact on marine and coastal ecosystems and recently its negative effect on freshwater ecosystems within the river basins has been recognized (Prosser *et al.*, 2001). In particular sediment export from river basins along the coast of North Queensland receives a lot of attention, because it directly affects the Great Barrier Reef World Heritage Area (Wasson, 1997).

The flood plains of the tropical North Queensland river basins are predominantly used for sugarcane cultivation. Because the sugarcane land lies adjacent to diverse and important marine and terrestrial ecosystems, it is often suspected to be an important contributor to excess sediment loads. Geomorphologically most flood plains are considered sediment storage entities, because of their low slopes and the low flow velocities of flood water (Asselman & Middelkoop, 1995). From this point of view little sediment export is expected from the lowlying sugarcane lands. However, observations of high turbidity in local streams during monsoonal summer rainstorms suggest considerable soil loss from the North Queensland cane lands.

In the 1980s green cane harvesting–minimum tillage was introduced on the cane fields as an erosion control measure. This type of harvesting is now applied in 95% of the cane growing area. Although the method was thought to minimize soil erosion from fields (Prove *et al.*, 1995), high sediment concentrations are still observed in runoff from the cane land. This raises the question whether there might be unrecognized sources of sediment in lowlying sugarcane land.

The present study aims to quantify sediment export from sugarcane land and identify the specific sources and sinks of a range of typical landscape elements in a North Queensland flood plain. A sediment budget is used to present both the sediment load observed in local drains, and the relative contribution of the potential sediment sources, which is estimated with traditional erosion measurement methods. A possible explanation for the observed processes is included in the discussion.

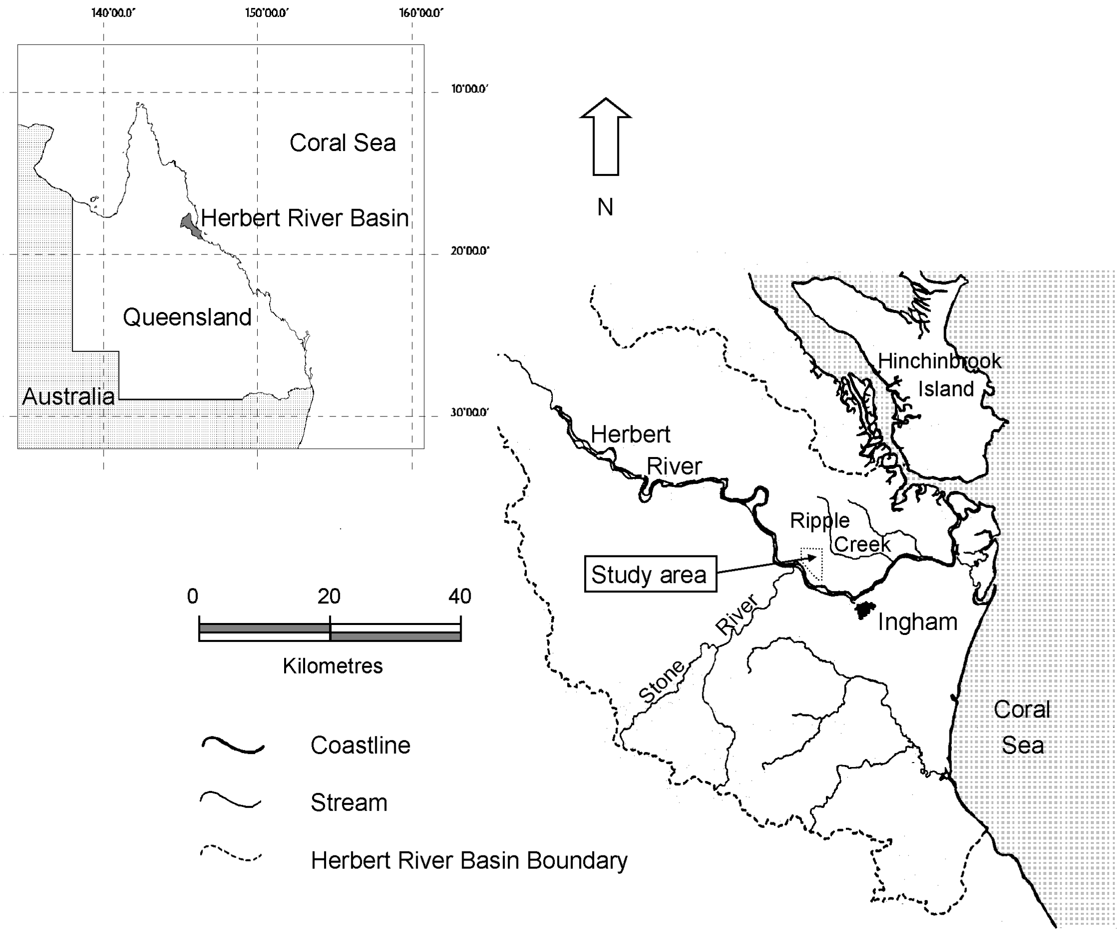

Fig. 1 Location of the study area in the Herbert River basin, North Queensland, Australia.

SITE DESCRIPTION

The flood plain

The study area is a 5.4 km^2 segment of the Ripple Creek basin. Ripple Creek is a tributary of the Herbert River, one of the major rivers along the North Queensland coast (Fig. 1). On the south side the Ripple Creek basin is bounded by levees of the Herbert River. The north boundary is the watershed of the Mt Leach range. Around 60% of the study area is used for sugarcane cultivation located in the flat lowlying part of the basin. The remainder of the area consists of steep forested uplands.

The Ripple Creek area receives slightly more than 2000 mm of rainfall each year. Most of this rainfall is the result of tropical cyclonic disturbances during the wet summer season from November to May. During cyclone events that generate extremely high rainfall in the upper part of the Herbert River basin, flood water from the Herbert River can inundate the lowlying areas of the Ripple Creek basin. The latest event of this extent occurred in 1977. Although in most years water from the Herbert River does not overflow into the Ripple Creek basin, a combination of high runoff from the uplands and local severe rainfall inundates large parts of the lowlying area several times each year. This frequent type of flooding can be increased by backwatering of the Ripple Creek discharge against high flows in the Herbert River.

The potential sources

Lowlying sugarcane land has a number of common landscape elements; each of these elements could potentially be a source of sediment:

(a) *Plant cane fields*: fields with a first year crop. The soil surface beneath the plant cane crop is still bare. Sheet erosion can be expected.

(b) *Ratoon fields*: sugarcane is grown for up to four return cycles called "ratoon". The soil surface beneath the ratoon crop is protected with a thrash cover from earlier harvests, but sheet erosion might still occur.

(c) *Water furrows*: shallow trenches in fields for improved drainage. Concentrated field runoff that flows through furrows could easily scour the bare surface.

(d) *Drains*: because of the low gradient in a flood plain environment, a dense drainage network is necessary to quickly drain the high volumes of rainwater. Bank erosion can be a major sediment source in lowland drainage systems (Laubel *et al*., 1999).

(e) *Headlands*: 2–5 m wide strips of land along the margins of cane fields, used for the turning of cane harvesters and as access roads. Their slightly sloping surface and sometimes sparse grass cover can make them susceptible to rill and sheet erosion.

METHODS

The sediment budget

Although drain water in the cane areas appears turbid under summer flow conditions and localized signs of land degradation are clear, overall rates of sediment movement are expected to be small. Application of traditional plot scale erosion measurement methods can provide direct estimates of surface level change in the studied landscape elements. When extrapolated over larger areas however, plot scale information is likely to introduce large errors due to spatial variability or insufficient accuracy of the measurement techniques. Alternative erosion measurement methods such as tracers are considered more reliable (Collins *et al.*, 2001). Application of tracers did not seem straightforward in this particular environment and information about processes was required along with flux estimates. Therefore it was decided to apply traditional methods within the framework of a sediment budget.

Sediment budgets have been applied in soil erosion research for various reasons. Often budgets are calculated to quantify, by difference between inputs and output, the hard to measure sediment storage component for a particular area (Walling, 1999). Rarely is a budget fully closed with an estimate for each of the budget components (Sutherland & Bryan, 1991). In this study all components of the sediment budget are estimated for the Ripple Creek area, so the budget equation can be used to test estimates of total sediment export and storage in the study area. Inequality between both sides of the equation will show mis-estimates of the budget components, for example as a result of measurement errors.

The following budget equation is used:

$$I - \Delta S = O$$

where I is the input of sediment from the various potential cane land sources plus the input of sediment from outside the agricultural land (i.e. from creeks draining the forested upland); ΔS is the change in the amount of sediment stored within the cane land area. Input I minus the change in storage ΔS should equal output O, which is the amount of sediment leaving the basin in the runoff via outlet drains.

Measurement methods

Landscape elements that could act as sediment sources together cover almost the complete surface of the studied area. At least some of these landscape elements will therefore be sinks. These can be temporary, permanent, partial or full sinks. The methods used to quantify the surface level changes in each of the landscape elements are chosen for their ability to register both current erosion *and* deposition processes. Exceptions are the gauged flumes that record the input from the fields and the streamgauge used to estimate input from the forested upland. These methods only

Table 1 Measurement techniques used to quantify the sediment budget components.

Budget component	Landscape element	Measurement method
Input I and change in storage ΔS	Plant cane fields	Gauged flumes
	Ratoon fields	Gauged flumes
	Headlands	Erosion pin plots
	Drains	Surface profiles
	Water furrows	Surface profiles/erosion pin plots
	Forested upland	Gauged upland creek
Output O		Gauged outlet drain

provide net input values. A detailed description of the measurement techniques used to quantify each of the budget components (Table 1) and further methods for data analysis can be found in Visser (in prep.).

RESULTS

The results presented here were obtained from field observations during the wet summer season from 1 December 1999 to 31 May 2000. Over this period the budget input for ratoon fields, estimated from gauged flumes, was 157 t of suspended sediment. The input estimated for planted canefields was considerably higher (666 t). The plot-scale erosion and deposition measurements with pins and profiles indicated the highest budget input was from water furrows (738 t). Most storage was measured on the headlands (597 t). The contribution by each landscape element to the input and storage component of the budget are specified in Table 2. Table 3 shows the total value for each side of the budget equation and the difference. Figure 2 shows a schematic representation of the total sediment budget. The values in the budget only represent the suspended sediment load. Bed load is not included. For this research suspended sediment is assumed to consist of particles smaller than 20 μm.

Table 2 Results of the measurements of input I and storage ΔS for the various landscape elements over the period 1 December 1999 to 31 May 2000.

Landscape element	Input I (t)	Storage ΔS (t)	Net input ($I - \Delta S$) (t)
Ratoon	157*	-	157
Planted cane	666*	-	666
Water furrows	738	369	369
Drains	533	412	121
Headlands	299	597	–298
Upland	269*	-	269
Total	2662	1378	1284

* Measurement techniques used in these landscape elements did not allow for separate estimation of erosion and deposition. The values shown are net values for *I*.

Table 3 Input values for the sediment budget equation and their difference.

Budget component	(t)
($I - \Delta S$)	1284
O	1509
Difference	225

Output component O of the sediment budget, which was estimated at the outlet drain, shows that 1509 t of suspended sediment left the area during the studied season. Of this total, 1240 t (1509 t output minus 269 t of sediment originating from forested upland) is generated within the cultivated lowlands (60% of the 5.4 km^2 study area ≈ 320 ha) suggesting 3.9 t ha^{-1} soil loss from sugarcane land.

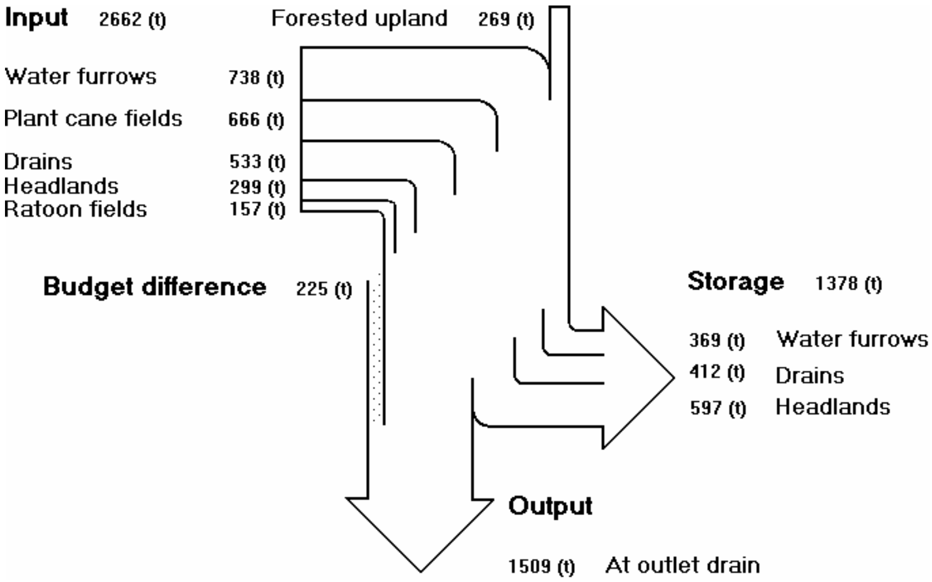

Fig. 2 Schematic representation of the sediment budget over the period 1 December 1999 to 31 May 2000 for the study area in the Ripple Creek basin.

DISCUSSION

The sediment budget shows that some landscape elements act as sinks in this flood plain environment, but overall the area is a net source of sediment. The discrepancy between the two sides of the budget equation (budget difference) could be the result of measurement error. Uncertainties for the budget components are expected to be considerable, but so far they have not been quantified properly.

Fields are the major source of sediment in the study area (823 t soil loss in total, Table 2). However most of this sediment originates from the plant cane fields (first year crop). During this cropping stage the soil surface is not yet covered with cane trash and therefore not protected against erosion. The second most important source of sediment in cane land are the water furrows. High volumes of concentrated runoff from tropical rainstorms that flow along the bare furrow surface can cause considerable erosion. Drains show on average almost as much deposition as erosion. Field observations suggested that the dominating process in a particular drain depends on both vegetation cover and the shape of the drain. In all landscape elements some storage was observed (where the measurement method allowed this observation), but headlands are the only element that act as a net sink for sediment. Headlands seemed to trap both sediment coming from the fields and from overbank flow of the drains. All the above information on the source/sink characteristics of the landscape elements in sugarcane land can be used for targeted soil management in lowlying sugarcane land.

It is remarkable that the lowlying cane lands are a source of sediment, despite their low surface gradient. A possible explanation is that the flood water that causes the frequent floods in the Ripple Creek basin consists of runoff from the forested uplands and high intensity tropical rain that falls directly onto the flood plain (rainfall in excess of 100 mm day^{-1} is common in this area). This water has a very low sediment concentration, so apart from material eroded locally at the flood plain, there is little sediment available for deposition. The large quantities of runoff however, do have enough force to cause erosion and can transport the eroded material out of the basin, as was shown in the budget. Therefore on a seasonal time scale the flood plain is a net source of sediment.

On a longer time scale the picture might be different. In the case of a major flood event in which flood water from the Herbert River inundates the Ripple Creek basin, there will be an additional supply of sediment from upstream parts of the Herbert River basin. Excess sediment in this type of flood water will be deposited under the slower lowland flow conditions and could result in net deposition on the flood plain. Such floods were however not experienced during this research, so nothing is known quantitatively about their effect.

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REFERENCES

Asselman, N. E. M. & Middelkoop, H. (1995) Floodplain sedimentation: quantities, patterns and processes. *Earth Surf. Processes and Landforms* **20**, 481–499.

Collins, A. L., Walling, D. E., Schingabula, H. M. & Leeks, G. J. L. (2001) Using ^{137}Cs measurements to quantify soil erosion and redistribution rates for areas under different land use in the Upper Kaleya River basin, southern Zambia. *Geoderma* **104**, 299–323.

Laubel, A., Svendsen, L. M., Kronvang, B. & Larsen, S. E. (1999) Bank erosion in a Danish lowland stream system. *Hydrobiologia* **410**, 279–285.

Prosser, I. P., Rutherfurd, I. D., Olley, J. M., Young, W. J., Wallbrink, P. J. & Moran, C. J. (2001) Large-scale patterns of erosion and sediment transport in river networks, with examples from Australia. *Mar. Freshwater Res.* **52**, 81–99.

Prove, B. G., Doogan, V. J. & Truong, P. N. V. (1995) Nature and magnitude of soil erosion in sugarcane land on the wet tropical coast of north-eastern Queensland. *Austral. J. Exper. Agric.* **35**, 641–649.

Sutherland, R. A. & Bryan, R. B. (1991) Sediment budgeting: a case study in the Katiorin drainage basin, Kenya. *Earth Surf. Processes and Landforms* **16**, 383–398.

Visser, F. (in prep.) Quantifying and managing sources of sediment in low-lying cane lands. PhD Thesis, Australian National Univ., Canberra, Australia *or* http://cres.anu.edu.au/~fleur.

Walling, D. E. (1999) Linking land use, erosion and sediment yields in river basins. *Hydrobiologia* **410**, 223–240.

Wasson, R. (1997) Runoff from the land to the rivers to the sea. In: *The Great Barrier Reef: Science, Use and Management* (ed. by N. Turia & C. Dalliston), 23–41. Great Barrier Reef Marine Park Authority, Townsville, Australia.