The Role of Non-Structural Options in the Management of Laterally Unstable Streams in North-Eastern Queensland

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ABSTRACT: *Many rivers in north-eastern Queensland are naturally prone to lateral instability due to meander migration, cutoffs, avulsion, and fluctuations in channel width. Conflicts between these processes, and assets which are fixed in location have led to management problems. Traditionally meander migration has been addressed by works aimed at arresting stream movement. It is argued that a non-structural approach may be more appropriate in some situations for economic and/or environmental reasons. A preferred management strategy would include structural and non-structural approaches.*

1. INTRODUCTION

Lateral instability is a significant management issue on the rivers and streams which flow across the coastal plain of north-eastern Queensland. Channel changes apparent over the period of European settlement include shifts in position resulting from meander migration, cutoffs and avulsion; as well as fluctuations in channel width in response to temporal variations in streamflows and flooding.

Climatic, hydrologic and physiographic factors pre-dispose these rivers and streams to channel instability. The area is subject to tropical cyclones, which are often associated with major flooding. Interannual streamflow and flood variability is high, especially in the less humid areas (Finlayson and McMahon, 1988); and phases of above- and below-average streamflows and flooding have been observed (Gourlay and Hacker, 1986), similar to those reported in south-eastern Australia (e.g., by Erskine and Warner; 1988; Brizga et al, 1993). The major coastal streams rise in mountainous terrain of the Great Dividing Range, and then plummet steeply down to the coastal plain. High relief and steep slopes set the scene for mass movements such as landsliding, which lead to episodic influxes of sediment into the waterways.

Many of the major streams of north-eastern Queensland are also large by overall Australian standards, for example, the Burdekin River at Home Hill has a catchment of 130,000 km^2 and a channel 750 m wide. Minor alterations in channel planform can thus result in considerable bank retreat, as viewed from a human perspective.

The expectations of the early settlers were influenced by their experience of the relatively stable or tamed streams of Britain and Europe. Community attitudes to waterway management have long been underlain by the expectation that river channels should be laterally stable, an expectation not met by the natural behaviour of many of the streams of north-eastern Queensland. Problems have arisen because of the conflict between dynamic natural channel and floodplain processes, and assets which are fixed in location (e.g., cane fields, roads, tramways, bridges, remnant vegetation). River management in north-eastern Queensland, as in the rest of Australia, has historically had a focus on structural measures as a means of dealing with bank erosion and other forms of channel instability.

The desirability of total stabilisation of rivers has been questioned in recent years. European studies have revealed ecological problems resulting from channel stabilisation, such as ecological simplification favouring later successional stages of ecosystems which under natural conditions would have been "reset" by reworking of the stream bed and floodplain (Roux et al, 1989). In the Netherlands, works are being carried out to provide for some limited channel instability to maintain or restore ecological diversity (Nieuwenhuijzen et al, 1993).

Waterway managers are today faced with a broad objective: to maintain or restore waterways to a condition which can sustain viable utilitarian uses and protect significant remnant aquatic and riparian habitat, whilst taking all opportunities to enhance overall environmental quality.

This paper examines the management of meander migration on rural streams, using a reach of Cattle Creek as a case study. A structural approach is outlined and evaluated using benefit-cost analysis, non-structural alternatives are considered and then a preferred management strategy is briefly described. The management of other forms of lateral instability is beyond the scope of the present paper, although it is recognised as an important issue.

2. THE STUDY AREA

Cattle Creek is a major tributary of the Pioneer River, which flows through the city of Mackay in north-eastern Queensland (Figure 1). Cattle Creek rises at Eungella at an elevation of more than 700 m, and to the north, south and west the catchment is bounded by mountainous terrain. Extensive deposits of Quaternary sediments are found within the valleys of Cattle Creek and its major tributaries, although outcrops of older basement rocks such as the Carboniferous-Mesozoic rocks of the Urannah Igneous Complex are exposed in the stream beds in some areas.

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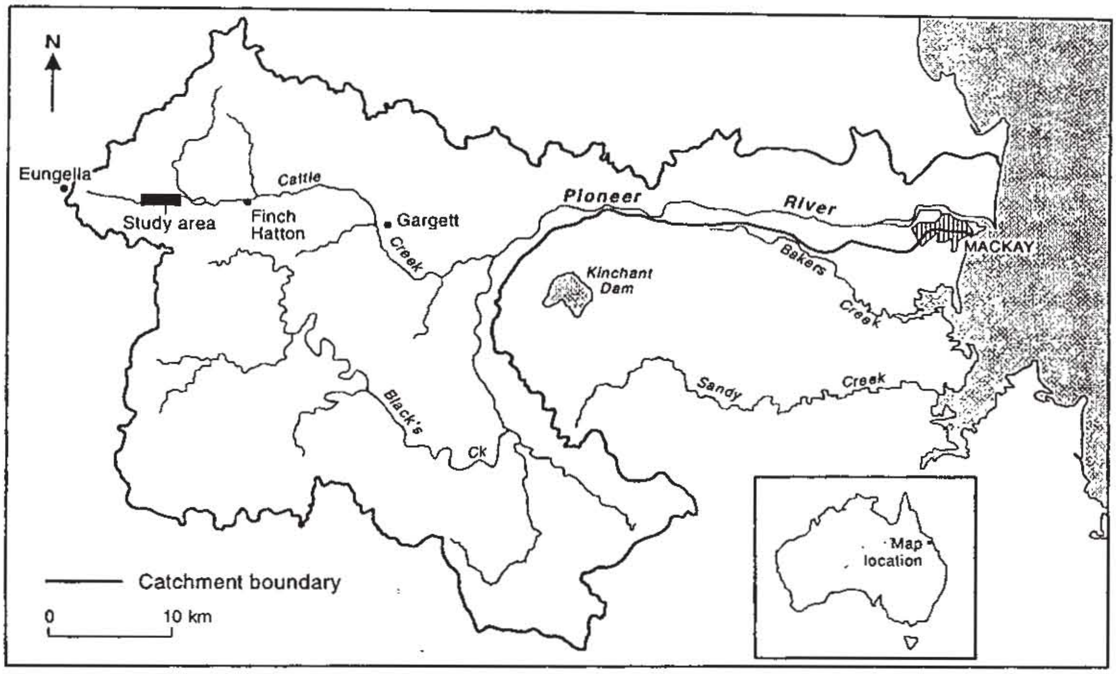
Figure 1: Location of Cattle Creek, North Queensland.



The steep headwater areas of the catchment retain their forest cover, and much of this is protected in the Eungella National Park. The lower hills and floodplains and terraces are used for cane growing and grazing.

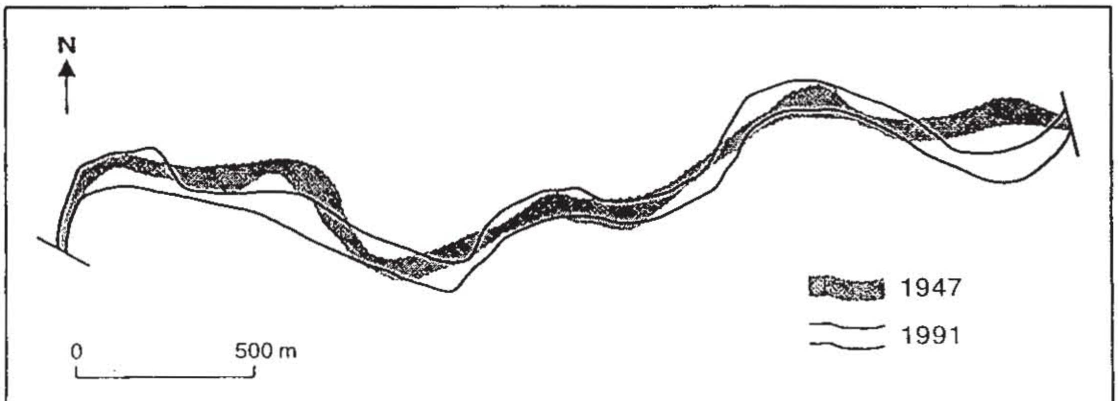
2.1. Geomorphological Processes

Cattle Creek has a history of being troublesome to waterway managers and adjacent landholders. A review of historical data including comparisons of recent and historical aerial photographs carried out by the senior author (reported in GHD, 1995) revealed changes in channel position resulting from meander migration and avulsion. Expansion and contraction of channel width associated with temporal variations in flood activity was also observed. Influxes of landslide debris have led to catastrophic changes, especially at the upstream end of the valley where steep tributaries fall directly into Cattle Creek. Bed degradation has generally not been a problem in Cattle Creek because of the control exerted by bedrock outcrops.

A reach of Cattle Creek between Morugo and Boongana was chosen as a case study (see Figure 1 for location). Differences in channel position between 1947 and 1991 are documented in Figure 2. Changes in bank position over this time period are generally associated with downstream meander migration. Fluctuations in channel width have also occurred, although over shorter timescales. The total area of land affected by stream processes over the period 1947-1991 was 17 hectares.

Downstream meander migration is an inevitable natural process along sinuous high energy alluvial channels. Cattle Creek and its valley are steep, and the floodplain is generally narrow and confined, thus stream power per unit area is high during floods. The bank sediments are in many places unconsolidated sands and gravels similar to those sediments being carried by Cattle Creek. Such materials have little resistance to erosion.

Figure 2: The high flow channel of Cattle Creek between Morugo and Boongana in 1947 and 1991, based on aerial photographs.



3. STRUCTURAL MANAGEMENT OPTIONS

3.1. Management Techniques

Structural techniques used in the management of bank erosion on rural streams in north-eastern Queensland include bank protection and alignment training works. Bank protection works include techniques which artificially increase the resistance of banks to erosion (e.g., rock riprap lining) and techniques which divert or deflect flows from eroding banks (e.g., groynes, retards and embayment works). Alignment training works are aimed at modifying the channel to create a supposedly stable meander pattern by selectively altering hydraulic resistance. Detailed discussions of these and other structural techniques can be found elsewhere (e.g, Working Group on Waterway Management, 1991).

Structural techniques which have been employed on Cattle Creek include realignment and stream clearing for the purposes of alignment training, and various forms of bank protection works including embayment works, groynes, and rock riprap lining. These works have met with varying degrees of success.

Rock riprap lining has several variants ranging from toe protection to full lining of the bank height. This technique is generally found to be effective in all its various forms on Cattle Creek and other nearby streams. It has also been recommended as the preferred technique on other streams in north-eastern Queensland, such as the O'Connell River (Oates, no date). Rock riprap lining has not been the only successful technique, for example, both impermeable and permeable groynes have been successfully used to stabilise eroding banks at sites along Cattle Creek. However, groynes can be relatively expensive in this environment because of the extent of ancillary works required.

3.2 Management Scenario

To assess the likely benefit of major structural works intervention, the rock riprap lining option was applied to the 3.3 km long reach of Cattle Creek between Morugo and Boongana. The premise is that if such lining was carried out in 1947, then the observed movement of the creek thereafter to 1991 could have been avoided, with the benefits realised as avoidance of loss of land and production on the areas known to have been affected by meander processes over the period.

In reality it is debatable whether total stability could indeed be sustained over a protracted time period on such a dynamic stream as Cattle Creek, in particular whether arresting meander migration in this way would lead to other forms of channel instability such as splay development or avulsion in the reach in question, and whether there would be adverse impacts downstream.

Based on aerial photograph measurements, approximately 2.85 lineal km of riprap lining of outer banks on bends would have been required to stabilise the channel, at an average cost of $120 per lineal m. This would provide for rock lining up to a maximum of two thirds of bank height. The areas of land "saved" from meander processes totalled 17 hectares for the period 1947-1991. The ongoing maintenance costs for such work could be expected to average no more than 5% per annum ($6 per lineal m of lining), including repair of flood damages.

3.3. Economic Evaluation

In theory the net worth of any project is determined by assessing and comparing all social, economic and environmental issues and values. Techniques such as Benefit-Cost Analysis (BCA) are commonly used, but application is often hindered by the fact that whilst implementation costs are readily measurable, many of the benefits and indirect costs are often difficult to quantify in monetary terms.

It is not the intent of this paper to enter into debates regarding quantification/valuation criteria for social and environmental issues, nor to distinguish between public and private investment, but instead to keep the focus on the direct valued monetary costs (build and maintain) and benefits (land production value). For projects which aim to protect only commercial productive assets like small amounts of farm land the benefits gained are equivalent to the net value of production.

Table 1 summarises the costs and general data associated with stabilising Cattle Creek in the study reach between Morugo and Boongana. Table 2 displays: 1) the total Net Present Value (NPV) for stabilisation works given three different discount rates; 2) average annual discount cost over fifty years; and 3) the average annual per hectare cost over fifty years. For the purposes of this paper it is assumed that the only threat posed by erosion is to farmland. As a result, other social and environmental values are not considered here.

Table 1: Summary of key data for rock riprap stabilization works in Cattle Creek between Morugo and Boongana.

Length of reach:	3.3 km.
Length of works: bank	2.85 lineal km of
Unit cost of works:	$120 per m
Total cost of works:	$342 000
Annual maintenance provision (%):	5% of capital cost
Annual maintenance Provision ($):	$17 100
Total area protected:	17 ha.

The net value of the land to be protected is dependent on two factors: 1) the price of sugar; and 2) the costs of production. The price of sugar is dependent on a range

Table 2: Cost of rock riprap stabilization works in the Cattle Creek study reach.

Discount Rate	3%	6%	10%
NPV of works	$778 078	$610 599	$511 398
Average Annual Cost	$10 703	$10 019	$9 359
Average Annual Cost per ha of Land Protected	$630	$590	$551

of variables such as: 1) currency exchange rates; 2) the international price of raw sugar; and 3) the quality of the cane grown. This study will consider three sugar price scenarios: 1) the peak price in 1980, A$630/T (current dollars); 2) the average sugar price from 1980-1992, A$403/T; and 3) the average expected international price of raw sugar, A$300/T, assuming an average A$/US$ exchange rate of US 75c (Hafi et al, 1993).

Table 3 contains the NPV of the benefits of protecting the 17 ha of cane land in the study reach given these three scenarios and the range of discount rates in Table 2. The values in Table 3 are based upon published data and a number of assumptions. First, the cost of milling sugar (including interest and depreciation) was assumed to account for about 80% of the gross value to the mill sector. Second, the usual distribution of the gross value of sugar was taken, 66% to the growers and 34% to millers (in 1980 the exact distribution for that year was used: 63.1% to the growers and 36.9% to millers). Third, it was assumed that 7.2 tons of cane yields one ton of raw sugar (Powell and McGovern, 1987), and at Cattle Creek each hectare produces 117 tons of cane (Sutton and Cairns, 1986). Finally, the average farm size at Cattle Creek was taken to be around 225 ha and that therefore the cost of growing one tonne of cane is roughly $22, including interest and depreciation (Industry Commission, 1992).

By comparing the benefits with the cost of protection it is possible to determine on economic grounds when and if riprap lining is justified in this example. The respective Benefit-Cost ratios are displayed in Table 4. These ratios indicate that if sugar prices were to remain at the high values that predominated before the slump in the 1980s then protection would be warranted. In Scenario 2 the situation is less clear, indicating that at these prices the use of structural stabilisation is of marginal value. Consequently, in such a situation cost competitive alternatives should be considered. In Scenario 3, the Benefit-Cost ratios are well below one, indicating that creek stabilisation using rock riprap lining would not be a judicious use of funds if productive value were the sole consideration.

Table 4: The Benefit-Cost Ratios of protecting 17 ha of cane land at Cattle Creek under three sugar price and discount regimes.

	3%	6%	10%
Scenario 1	4.18	3.36	2.62
Scenario 2	1.28	1.02	0.80
Scenario 3	0.56	0.45	0.35

Table 3: NPV of protecting 17 hectares of cane land along Cattle Creek, the average annual benefit, and the average annual per hectare benefit, for three discount rates.

Scenario 1: Sugar Price = $630/T			
Discount Rate	3%	6%	10%
NPV of benefits	$3 252 840	$2 050 704	$1 338 650
Average Annual Benefit	$65 057	$41 014	$26 773
Average Annual Benefit/ha.	$3 827	$2 413	$1 575
Scenario 2: Sugar Price = $403/T			
Discount Rate	3%	6%	10%
NPV of benefits	$992 222	$625 532	$408 332
Average Annual Benefit	$19 844	$12 511	$8 167
Average Annual Benefit/ha.	$1 167	$736	$480
Scenario 3: Sugar Price = $300/T			
Discount Rate	3%	6%	10%
NPV benefits	$437 516	$275 825	$180 052
Average Annual Benefit	$8 750	$5 517	$3 601
Average Annual Benefit/ha.	$515	$325	$212

The Benefit-Cost Ratios reported here are only applicable to the channel migration rates and scale of works outlined for this example, and could be expected to vary in other situations.

Other factors which would need to be taken into account in any specific decision include:

- social and cultural values associated with land ownership (extra benefits);
- protection of infrastructure such as roads, tramways, bridges, weirs, underground or overhead services (extra benefits);
- environmental losses associated with bank lining - where erosion processes are natural in origin the reworking of bank sediments and riparian land is part of the natural ecosystem; suppression of these processes may have detrimental effects through interruption of downstream sediment delivery, exacerbation of alternative (possibly catastrophic) erosion processes, ecological simplification etc. (extra costs);
- protection of remnant intact indigenous riparian zones (extra benefits).

4. NON-STRUCTURAL OPTIONS

Non-structural approaches to management are advocated for consideration in situations where major assets and the highest value farmland are not threatened.

The non-structural approach is not a do-nothing approach. It is a redirection of effort and resources. Two examples of proactive non-structural management of channel instability are outlined: 1) erosion hazard mapping, and 2) "Buy-back-lease-back" arrangements. This discussion is not intended to be an exhaustive review of non-structural options.

Inundation hazard mapping is a widely accepted tool in the management of flooding. Dunne (1988) outlined a North American example where information on areas likely to be affected by future channel migration was incorporated into land use planning. Erosion hazard mapping for the management of bank erosion would involve the identification of areas subject to various levels of risk of meander migration and other channel processes. Land uses could then be zoned in such a way that they are compatible with risk levels, and prospective purchasers of properties bordering waterways could be warned of inherent risks. In the case of land which is currently privately owned, considerations of fairness and equity indicate that mapping and zoning would need to be accompanied by financial offsets for any reduction in property values. An understanding of geomorphological processes is crucial to effective and credible erosion hazard zoning.

"Buy-back lease-back" arrangements have been used in Australia and overseas in the management of land subject to inundation. Such a system has potential for application to the management of land currently in private ownership which is subject to meander processes. It would involve the purchase of land by interested parties (possibly but not necessarily the waterway management authority; other potential sponsors could be community organisations such as conservation groups). The land could be leased back to adjoining landholders for cane production at a rental which reflects the risk of erosion, on the proviso that erosion losses could not be claimed. Alternatively, it could be leased back for environmental enhancement purposes.

A lease-back system would also help address the problem that when a stream migrates, land is "lost" on the outer bank of the bend, but "gained" on the inside bank. Under a lease arrangement, the landholder on the outer bank does not sustain as great a loss as they would if they owned the land, and the landholder on the inside bank has the option to lease the additional land "gained" as the result of meander processes.

5. A PREFERRED MANAGEMENT STRATEGY

A preferred strategy for managing lateral instability would be based on the premise that the most appropriate land use for stream banks and verges is as a zone of indigenous vegetation, but would also take into account precedents set by past management operations, as well as current physical, economic and social constraints. Such a strategy includes the following key elements:

1. Encouraging gradual withdrawal of intensive cultivation from those parts of the floodplains which are subject to active erosion and deposition.
2. Encouraging regeneration of indigenous vegetation in the riparian zone and on the active parts of the floodplains. Limited clearing of fast growing vegetation in the channel may be necessary to reduce the probability of splays or avulsions.
3. Employing erosion control works only where significant assets, high value farmland, infrastructure, or remnant riparian vegetation are threatened, or are likely to be threatened in the short-term by continuing meander progression.
4. Utilizing savings from any reduction in structural works activities to support landowners/occupiers whose livelihood may be threatened from time to time through progress of ongoing stream processes.

6. CONCLUSIONS

Many rivers and streams in north-eastern Queensland are naturally subject to lateral instability due to meander migration, cutoffs, avulsion, and fluctuations in channel width related to flood activity. This paper has focussed on options for the management of meander migration, with particular reference to Cattle Creek. It is argued that a preferred management strategy for Cattle Creek and similar streams should include structural and non-structural measures. Structural works are necessary for protecting valuable assets (including high value farmland) and infrastructure. However, proactive non-structural approaches should be considered in situations where economic or environmental considerations contraindicate the use of structural works. Appropriate non-structural measures may include: 1) erosion hazard mapping, or 2) "buy-back lease-back" arrangements for land subject to stream erosion hazard but currently in private ownership. Overall, this analysis reveals the need for systematic multidisciplinary evaluation of river management options, including structural and non-structural approaches, in agricultural settings.

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