Channel Change, Bank Stability and Management for North Queensland Coastal Streams

Ross Kapitzke*, Scott Smithers** and John Lowry**

ABSTRACT: *The flow regimes and catchment physiographies that characterise north Queensland coastal streams differ from those of other regions in Australia and overseas. The pressures of urban and agricultural development are increasing in this area which has significant natural conservation value. In spite of this, records of basic process data and quantitative information on the condition of the streams are seriously deficient in spatial coverage and historical extent. Little information is presently available on the relative significance of bank instability problems and of the suitability of particular bank stabilisation practices for the region. This paper reviews streambank stability for the region in terms of the 'State of the Environment' pressure-state-response model and outlines research and development activities that are leading to new stream management approaches. The research outcomes are significant for stream management in other humid tropical environments.*

1 INTRODUCTION

The streams of coastal north Queensland drain catchments with markedly varying geomorphologies, geologies and vegetation covers and are subject to diverse climatic and hydrologic regimes. Agricultural and urban development have affected the quality and stability of many of these streams, particularly over the relatively fertile lowland coastal plains. Many of them link two ecosystems of international significance, namely the Wet Tropics Rainforest and the Great Barrier Reef, and so it is critical that appropriate management strategies for the streams be developed and implemented. Recent reviews of Australia's fluvial systems (Tooth and Nanson 1995; Rutherfurd et al, in review) state that there is very little process data and quantitative information available for these streams.

This paper reviews bank stability for north Queensland coastal streams between Mossman, just north of Cairns, and Mackay. We follow the SoE reporting framework and use the OECD's pressure-state-response model. The model assesses the impact of human settlement and activity on rivers (pressure), present stream condition (state), and human responses to these conditions (response) (Rutherfurd et al, in review). The object of this review is to: i) describe the status of the streams; ii) identify the shortage of basic stream process data; and iii) emphasise the need for appropriate stream management practices for the region. We also outline research and development initiatives which respond to Tooth and Nanson's (1995) timely call for studies that take account of local 'hydrological peculiarities', and of relationships between the biological and physical components of fluvial systems.

2 REGIONAL CHARACTERISTICS

The study area encompasses 16 coastal river basins between the Daintree River in the north and the Pioneer River in the south (Figure 1). A great variety of climatic, hydrologic, and geomorphic conditions occur throughout the region, which encompasses three distinct biogeographies: the wet tropics (north from Ingham), the dry tropics (Proserpine to Ingham) and the moist central coast (Proserpine and Mackay).

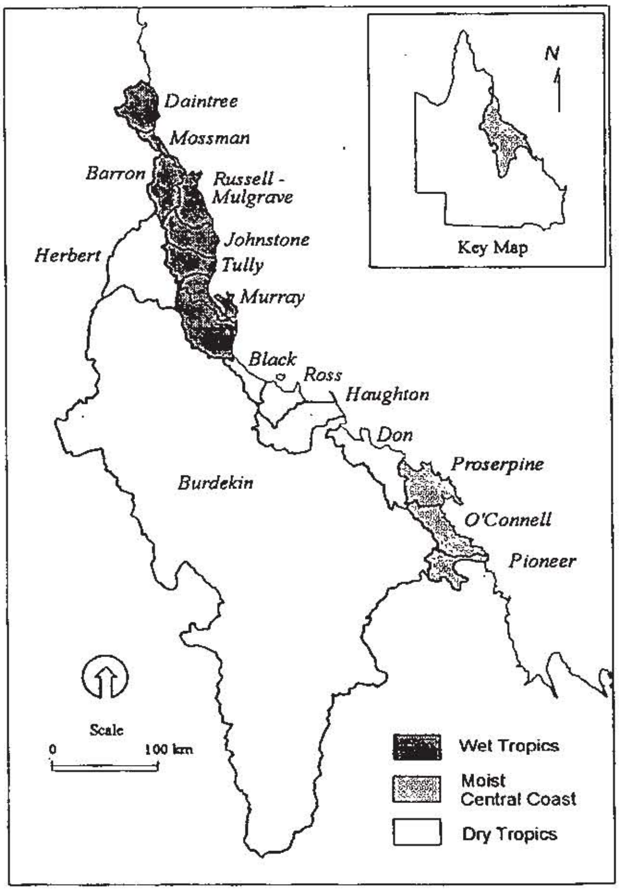

Figure 1 - North Queensland Coastal River Basins

* Department of Civil & Systems Engineering, James Cook University of North Queensland, Townsville, Qld 4811
Telephone: (077) 814 810 Fax: (077) 751 184 Email: Ross.Kapitzke@jcu.edu.au

** Department of Tropical Environment Studies & Geography, James Cook University of North Queensland

2.1 Climate

The region's climate is characterised by hot humid summers (December to April) and mild winters, with temperatures generally in the range 24-33^0 C and 15-30^0 C respectively. Monsoonal troughs commonly affect the region during summer and can develop into tropical depressions that produce high intensity, long duration rainfalls. Occasionally these depressions deepen further to form tropical cyclones with extremely high rainfalls (Bonell 1988). Accordingly, the region experiences high spatial, seasonal and inter-annual variability in rainfall.

The spatial variation in average annual rainfall throughout the study area is shown in Table 1. Average annual totals range from approximately 500 mm in the southern parts of the Burdekin catchment to more than 6000 mm in the Mulgrave-Russell catchment on the Bellenden Kerr Range (Hausler 1990). Inter-annual variability in rainfall is high, particularly in the dry tropics where droughts periodically occur. Rainfall throughout the region is strongly seasonal; even in the wet tropics 63% of the annual total is monsoonal (Bonnell 1983). Daily totals commonly exceed 250 mm, and both short and long duration high intensity falls may occur, alternating with periods of dry weather.

2.2 Hydrology

The coastal drainage basins range in size from 490 km^2 (Mossman River) to 129 000 km^2 (Burdekin River). The Burdekin, Herbert and Barron river basins are bounded to the west by the Great Dividing Range, whilst the remaining basins have their headwaters in the lesser coastal ranges. These configurations, coupled with the regional climatic variations, generate considerable diversity in catchment hydrology.

Spatial, seasonal and inter-annual variability in streamflow largely follows that of rainfall. Table 1 shows the marked variation in annual runoff volumes and rainfall/runoff percentages between streams within the three biogeographic zones. Whilst seasonal variability in streamflow is typical of many Australian streams (Finlayson & McMahon 1988), it is particularly pronounced in the study region. All streams have a distinct summer maximum flow. Streams north of the Herbert are mostly perennial, whereas south of this the flows are typically intermittent (Hausler 1990).

Table 1 - River Basin Hydrology

River Basin (Area - km^2)	Mean Annual Rainfall (mm)	Mean Annual Runoff (1000 ML)	Runoff / Rainfall (%)	Max. Instant. Flow ^{a} (m^3/s)
Daintree ^{w} (2125)	2576	3560	65	–
Mossman ^{w} (490)	2459	687	57	–
Barron ^{w} (2175)	1447	1153	37	4556
Mulgrave - Russell ^{w} (2020)	3233	4193	64	–
Johnstone ^{w} (2330)	3405	4698	59	–
Tully ^{w} (1685)	2970	3683	74	–
Murray ^{w} (1140)	2485	1628	57	–
Herbert ^{w} (10 131)	1331	4991	37	11 919
Black ^{d} (1075)	1510	509	31	–
Ross ^{d} (1815)	1071	372	19	–
Haughton ^{d} (3650)	923	756	22	–
Burdekin ^{d} (129 860)	640	10 100	12	35 999
Don ^{d} (3885)	1022	689	17	4983
Proserpine ^{m} (2485)	1562	1431	37	–
O'Connell ^{m} (2435)	1705	1668	40	–
Pioneer ^{m} (1490)	1418	994	47	9842

Notes: a) selected catchments only; w) wet tropics; d) dry tropics; m) moist central coast

(from Hausler 1990)

The nature of flooding in north Queensland is different to other areas in Australia (Fenwick 1982). Floods normally result from cyclonic or monsoonal activity, and the relatively steep stream grades and high rainfall intensities cause rapid flood rises to prominent peaks. A peak flood discharge of approximately 36 000 m^{3}s^{-1} was recorded at Clare on the Burdekin River in 1958. The inter-annual variability in flow is extreme for many streams. The coefficient of variation of the annual flows varies from 0.3 in the wet tropics to 1.2 in the dry tropics. The ratio of maximum to minimum annual flow volumes for the Burdekin River is 218, compared with 5.6 for the North Johnstone River (Hausler 1990).

2.3 Geomorphology

River basin landforms for the region are characterised by a coastal floodplain bordered to the west by ranges and high hills. In the wet tropics and to a lesser extent the moist central coast catchments,

Rutherfurd, I.D. & Walker, M. (1996). Proceedings of the 1st National Conference on Stream Management in Australia, 19 – 23 February, 1996, Merrijig, Australia.

the ranges are rugged and are separated from a narrow coastal plain by short upland to lowland stream transition zones. By comparison, the catchments of the dry tropics usually have lower relief, a wider coastal plain, and longer stream transition zones.

A diverse range of morphological forms and processes occur in the study area and broad generalisations on stream and floodplain systems are difficult. However, natural stream levees and backswamps are prominent on the coastal floodplains. Stream channel size and bankfull channel capacity typically decrease in the downstream direction in the lower reaches, and distributary flow channels and elevated natural levees present a threat of channel avulsion during overbank flow conditions.

3 PRESSURES ON THE STREAMS

Human development is placing increasing pressures on the streams in a region that has significant conservation value (eg Wet Tropics and Great Barrier Reef World Heritage Areas). The pressures are discussed here in terms of direct impacts (activities within the stream channels and riparian lands), and indirect impacts (activities within the catchment remote from the streams).

In the wet tropics and moist central coast areas the narrow alluvial plains and hills have been largely cleared of native vegetation and are extensively used for sugar cane production and other intensive cropping. *Eucalyptus* and mixed closed rainforests cover the mountains to the west, while dairying on improved and irrigated pastures is common in elevated areas in the Barron, Johnstone and Pioneer river basins. In the dry tropics, the coastal plains of the Burdekin, Haughton and Don river basins have intensive irrigated sugar cane and horticulture crops, and beef cattle grazing is prevalent in the hinterland areas, where the native vegetation typically includes *Eucalyptus*, *Melaleuca* and *Acacia* woodlands.

Major urban centres and other towns are situated on streams in the coastal lowlands, eg: Cairns (Barron River), Townsville (Ross River) and Mackay (Pioneer River). Tourism is now an important industry throughout the region.

3.1 Direct Impacts

Direct impacts on streams within the study area include flow regulation and water storage; channelisation and river improvement; aggregate extraction and mining; encroachment from agriculture, urbanisation and infrastructure; introduction of exotic fish and plant species; and recreation and boating.

Dams and weirs have been built on several of the major streams for water supply and irrigation (Barron, Ross, Haughton, Burdekin, Proserpine, Pioneer); hydro-power (Barron, Tully); and flood control (Ross, Proserpine). These reservoirs alter seasonal flow distributions and reduce flood frequencies, but may not reduce flood peaks and durations since flood volumes can be in excess of storage capacities. The larger dams affect downstream sediment supply, environmental flows and in-stream vegetation conditions.

'River improvement' activities, characterised by hard engineering techniques such as rock revetment, channel realignment, clearing and desnagging, have historically been carried out in all river basins in the region. Sand and gravel has been extracted from the Barron, Mulgrave, Black and Gregory rivers in particular. Alluvial mining was once practised in the upper areas of the Mulgrave-Russell (gold) and Herbert (tin) catchments, resulting in increased downstream sedimentation in these streams.

Sugar cane farming has severely modified drainage systems on the coastal plain. Many small streams have been relocated or completely filled and land development typically extends to the very edge of the major streams. Land clearing for farm development and inappropriate farm management practices such as spraying and burning have degraded riparian lands. The narrow riparian zone that remains offers little protection to stream banks and is commonly dominated by introduced plant species. It provides only low grade habitat and most often represents a fragmented, rather than continuous, natural corridor.

3.2 Indirect Impacts

Indirect impacts on the streams include modified water and sediment flow regimes from agriculture, forestry and urbanisation; and pollution from organic matter, biocides, heavy metals and nutrients.

Catchment erosion is a problem in the wet tropics and the moist central coast where widespread clearing of the coastal plain and hinterland has occurred from sugar cane and small crop farming. Cattle grazing in upper catchment areas, particularly in the dry tropics, has also accelerated soil erosion. Increased sediment supply, channel aggradation, and increased flood levels are causing concern to river managers.

Rainforest logging once had a significant effect on water quality and stream sedimentation in wet tropic areas (Bonell 1988), but changes in forestry practices and the declaration of the Wet Tropics World Heritage Area have since ameliorated these effects. However, agricultural fertilisers and chemicals and effluent discharges from sewage treatment and sugar mills continue to affect stream water quality. Improved farming and industrial practices have the potential to reduce nutrient export to the river systems, estuaries and the Great Barrier Reef lagoon.

4 STATE OF THE STREAMS

The degree of human impact on the natural system and the effect of natural and accelerated stream processes on human development can be evaluated from the state of the streams. The present physical condition of the streams in the region is described here in terms of the types and rates of channel change and associated bank instabilities.

4.1 Rates of Channel Change

The collection of information on the type and rate of channel change in north Queensland coastal streams enables researchers to predict present-day natural change, to understand the significance of human induced change, and to provide a chronological framework for estimating human effects on the fluvial systems. Information is required on short-term changes that have occurred since European settlement (past 150 years), as well as long-term changes occurring over a geomorphological timescale of thousands of years. A lack of long-term data means that it is difficult to determine whether channel changes in the region are naturally or artificially induced, or are due to episodic or cyclic events.

This review of rates of change data for the region uses two broad time scales: historical (approximately 150 years of European settlement) and mid - to - late Holocene (past 5000 years). The limited published material that does exist for the historical period consists mainly of aerial photographs, maps, field surveys and anecdotal data for the past 50 years. The lack of Holocene data demonstrates the need for an extensive program of stratigraphic sampling, dating and analysis.

Limited studies of historical rates of change have been undertaken in each of the river basins. For example, changes in channel morphology between consecutive photographic and mapping surveys of the Mulgrave River were described by Connell Wagner (1992). Connor (1987) used a series of aerial photographic surveys conducted over 40 years to note changes in the channel position, morphology, and surrounding landuses of the South Johnstone River. Records of historical and anecdotal data on flooding and channel change in the Burdekin River have been compiled by Medley (1993). For these studies, the cumulative changes in bank position over a period of 50 years were sometimes in the order of 10s to 100s of metres, but were commonly much less.

Other studies have been undertaken by Hopley (1970), who described the coastal geomorphology of the Burdekin delta using drill cores, aerial photographs, and ground surveys; and Pringle (1984) who described the evolution and rates of change of the east Burdekin delta coast between 1940 and 1980. Channel movements of several hundred metres have been recorded in the Pioneer River estuary within the comparatively short timespan of 150 years (Gourlay and Hacker 1986). Only the Burdekin (Hopley), the Don (Nolan and Casey 1981) and the Pioneer (Gourlay and Hacker) have been studied over Holocene time scales, using geological interpretation and stratigraphic dating. Even so, the limited extent of the long-term data makes it difficult to assess the significance of the contemporary changes.

4.2 Channel Change and Bank Instabilities

This section provides an overview of the various types of channel change (metamorphosis, accelerated channel migration, avulsion, bed degradation) and associated bank instabilities (fluvial erosion, mass failure, overbank erosion) that are common in the region. Information on the relative significance of the types of change and bank instability problems is scarce.

As far as we are aware, no major channel metamorphosis (complete change in channel morphology) has occurred in the region. Significant sedimentation has been recorded, however, in the lower reaches of many of the rivers, notably the Don River. Growth of instream vegetation has increased following flow regulation in the Barron, Burdekin and Proserpine rivers. Channel migration is most evident on the high sinuosity streams in the wet tropics such as the Russell, Tully and Murray. The Russell, Johnstone, Herbert, Haughton, Burdekin, Don, Proserpine and O'Connell rivers have a potential for channel avulsion. Bed degradation, while not significant in the main streams on the coastal plain, is a problem in the smaller streams and tributaries in the catchment headwaters where stream gradients are steeper.

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Bank instabilities are usually associated with one or more of the above morphological processes, but can also result from local channel processes, unrelated to the broader channel changes. Human impacts commonly play a large part in bank instabilities. Fluvial erosion occurs mostly on meandering streams where riparian vegetation is degraded and channel morphology is substantially altered. Such erosion is prevalent in all river basins and is of particular concern in the Daintree, Barron, Mulgrave, Russell, Tully, Haughton and O'Connell rivers. Mass failure is commonly associated with fluvial erosion and piping failure, and is prevalent on larger streams such as the Herbert, Burdekin and Pioneer. Overbank erosion is common on lowland streams with a tendency for channel avulsion, and is most severe where the land slopes significantly away from the streams, eg the Russell, Herbert, Haughton, Burdekin, and Proserpine rivers.

5 RESPONSE

In this section we assess the human response to bank instabilities. We focus on traditional and more recent stream management approaches and bank stabilisation practices, strategic planning studies and institutional arrangements.

5.1 Traditional Stream Management Approaches

Like other areas of Australia, stream management in the north Queensland region has traditionally been characterised by an engineering bias and an emphasis on structural methods without consideration of the full range of issues (cf Strom 1962). The principal objectives have been to mitigate against flooding and to check erosion (Fenwick 1982). A variety of bank protection, alignment training, and channel modification methods have been used, however their success has been affected by a lack of consideration of ecological values and geomorphic setting, by poor integration of physical and biological techniques, and by limited technical and economic suitability for the prevailing conditions.

Rock revetments are the most common physical protection works, and subsurface drainage is installed at some of these sites. Rock protected spillways are sometimes used for flood outflow control. Alignment training works include steel pile and wire mesh embayments and fields of groynes (typically rock). Channel modifications have in some instances involved pilot channel excavations and alignment cutoffs. Vegetative treatments have had limited success because of inappropriate species selection and plant establishment or maintenance techniques. Integrated physical (rockwork) and biological (vegetation) treatments have not been successful, and the introduction of vegetation, although intended as a means of stabilisation, has often merely improved the landscaping effect. Habitat and ecological aspects have traditionally been neglected.

5.2 Recent Developments

River improvement trusts were first established in Queensland in the mid 1940s (Burdekin River) to provide specialist management of flooding, erosion and sedimentation. However increased environmental awareness, altered community perceptions, and pending legislation changes, are changing stream management approaches in the region. The river trusts, constituted within 11 regions from Mackay to Mossman, have recently been engaged in the preparation of stream management strategies addressing key problem areas, appropriate methods and funding arrangements. An integrated catchment management (ICM) approach is being adopted, and five ICM groups have been established. Table 2 summarises the present river trust, ICM and strategic planning arrangements for the individual river basins.

Table 2 - River and Catchment Management

River Basin	River Trust [a]	ICM	Strategic Planning
Daintree - Mossman	√		√
Barron	√		√
Mulgrave - Russell	√	√	√
Johnstone	√	√	√
Tully - Murray	√	√	√
Herbert	√	√	√
Black - Ross			
Haughton	√		
Burdekin	√		√[a]
Don	√		
Proserpine	√		√
O'Connell	√		√
Pioneer	√	√	√

Notes: a) part catchment only

6 THE WAY FORWARD

An understanding of local environmental conditions and characteristic stream processes is necessary to satisfactorily address bank instabilities and degradation in north Queensland coastal streams. Furthermore, the development of appropriate stream management responses for the region depends on the knowledge of pressures on the streams (direct or indirect), the state of the streams (rates of change, bank instabilities, ecological condition), and the interrelation of these factors.

The dearth of fluvial research on north Queensland's coastal streams has historically reflected the remoteness of the region from population centres in south eastern Australia. Unfortunately, the deficiency of process data prohibits the development of rigorous local models for the unique and varied fluvial landscapes of the region. Hence, stream managers lack an appropriate theoretical context to guide their decisions.

This is presently being addressed through a number of research and development projects that are leading to new stream management approaches in the region. These projects involve integrated engineering, geomorphological and ecological studies, which include a review of bank stability problems and stabilisation practices, field monitoring and case study activities and implementation of various trial bank stabilisation techniques (Johnston et al 1994). Researchers, government agencies, industry, landholders and community groups are collaborating in these efforts. Through these research, planning, implementation and extension activities, the emphasis is shifting from traditional approaches to broader stream management values, ecosystem management and stream health.

We believe that these initiatives represent the way forward for stream management in the region. They also go some way towards addressing the shortcomings in fluvial research (Tooth and Nanson 1995) and the lack of stream data identified in the OECD *State of the Environment* reporting.

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