Stream Stabilisation for Rehabilitation in North-East Queensland

JAMES COOK UNIVERSITY

NATIONAL
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Development
Corporation

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Foreword

European settlement of Australia has brought about major changes to most of our river systems. The widespread clearing and grazing of catchments for agriculture, the construction of dams and weirs, and urban development have often resulted in changes in the way that rainfall runs off Australian landscapes, and in the capacity of stream channels to convey that flow. In catchments right across Australia there is ample evidence of these changes, many of which are degrading our river systems and their water resources. More frequent floods, loss of valuable riparian land, streambank erosion, silting of channels, and loss of instream habitat have all been identified by landholders and government agencies as causes for increasing concern. In response, there is a growing interest in improving the management of our river systems and, consequently, a demand for information about the causes of these problems and how to solve them - or at least reduce their impact.

Greater attention is now being given to streams as a vital component of Australian landscapes. Unfortunately, our knowledge of these systems, and particularly of the factors vital to the health of aquatic ecosystems, is not well-developed. We cannot always rely on information from other parts of the world because it is often not applicable to our unique ecosystems and their environments. We therefore need to research and understand our own river systems; to use that knowledge to provide practical support to individuals and groups with responsibilities for management of streams and their adjacent riparian lands.

The Land and Water Resources Research & Development Corporation (LWRRDC) is a Commonwealth body charged with funding research and development that will help lead to improved management of Australia's land, water and vegetation. This publication is a major product arising from an R&D project undertaken by a team from James Cook University with funding from LWRRDC, the National Landcare Program and the Queensland Department of Natural Resources. The project focuses specifically on the rehabilitation and stabilisation of coastal streams in north-east Queensland. An important factor in its success has been the close collaboration with shire councils, river improvement trusts and catchment management groups within the region.

The climate of the region includes extreme rainfall and runoff events associated with tropical cyclones, and this, combined with changes in landuse and urban development, has led to a range of problems. This publication explains how different types of development result in increased pressure on river systems and how the particular causes of local problems can be identified, and goes on to describe a range of management responses that meet best practice principles. It provides information on technical issues, and practical guidance in the design and implementation of streambank management projects. There is a strong emphasis on combining hydraulics and engineering with ecological expertise, so that the management practices proposed will meet the physical requirements for stabilisation as well as the long-term ecological requirements for rehabilitation and restoration.

Streambank Stabilisation for Rehabilitation represents a significant contribution to building knowledge and expertise in the region to meet a range of objectives in sustainable stream management. On behalf of LWRRDC, I congratulate the project team on this outcome of their work; work that will continue into the future. I also thank the other funding agencies, researchers, and other people who contributed to this project's success.

Phil Price
Executive Director
LWRRDC

Preface

Stream Stabilisation for Rehabilitation is a guide to good practice in stream stabilisation and rehabilitation of north-east Queensland coastal streams. The majority of existing stream management guidelines are not entirely suitable for that purpose. Many focus on approaches to streambank stabilisation that give scant regard to ecological or aesthetic objectives. Others provide little on the principles, procedures and methods essential to good practice. Many of the existing guides were developed for other environments, principally temperate North America and Europe. Until now, virtually nothing has been available for the quite different tropical stream systems, particularly those of north-east Queensland.

Stream stabilisation is one element of rehabilitation, and the methods and procedures presented here are strongly embedded in a stream rehabilitation framework.

This publication is not intended to replace the available source material in any of the relevant disciplines: it does not, for example, provide a text on stream habitat management or on design of particular treatments. Similarly, it is not a code or standard dictating a uniform design. Because requirements vary considerably from problem to problem and from stream to stream, this document does not purport to cover all situations. What this document does provide is a holistic conceptual approach which outlines the appropriate principles and procedures, and allows users to undertake individual assessments and adopt particular applicable practices.

Within these pages is a wealth of information, and we hope that the user will take the time to study the broader context of the document, not merely look for a quick-fix solution. For most practitioners parts of the document will be second nature, but other parts will introduce new concepts. It is important that practitioners, including consultants in specialised areas, have knowledge of the whole breadth of material presented here (the known and the new), if sound management strategies and treatments are to be adopted.

The principal aim of *Stream Stabilisation for Rehabilitation* is to help practitioners and managers develop improved practices for stream stabilisation and rehabilitation, to minimise any adverse effects of these projects, and to integrate environmental considerations into the planning, design and implementation process. *Stream Stabilisation for Rehabilitation* will also facilitate assessment of projects by approval agencies and, overall, should lead to more efficient and appropriate stream management decisions. While experts may need to be consulted for particular tasks, responsibility for identifying solutions to problems needs to be shared, and based on mutual understanding of the various facets of a problem.

The authors of this document are continuing research and consultancy in stream management. Specifically, the authors plan to convene hands-on training workshops at which approaches will be explored with practitioners; to investigate, in collaboration with researchers in other organisations, questions which emerged during the research for this document relating to management for economic and ecological sustainability, and to restoration of degraded systems; to undertake case studies in order to test and further develop procedures; to facilitate the reporting of related research and development projects through standardised procedures; to undertake research incorporating broader issues of maintenance and/or restoration of proper system functions; and to look at ways of improving inter-disciplinary communication and cooperation, based on the experience and knowledge gained during this project.

Stream managers are encouraged to fully document each stream management project they are involved with, in line with the structure of this publication. Reports so prepared will help researchers or reviewers build up a portfolio of case histories to better understand the efficacy of different treatments.

The authors welcome any feedback on the document. Comments should be sent to the authors at the address indicated on the title page.

Acknowledgments

Stream Stabilisation for Rehabilitation is the outcome of several research and development projects involving researchers, practitioners and federal, state and local government agencies. The work has been funded principally by the Land and Water Resources Research & Development Corporation. Other project funding has been provided by the Queensland Department of Natural Resources (formerly the Department of Primary Industries) and the National Landcare Program.

The work has been undertaken by staff of James Cook University in collaboration with agencies, consultants and other researchers throughout Australia. These collaborators have assisted with supply of information, with field investigations, with trials and with monitoring. In-kind support for the work has been provided by the Department of Natural Resources, the North Queensland River Trust Association, and individual river improvement trusts, most notably the Herbert River Improvement Trust, Cairns River Improvement Trust (formerly the Mulgrave Shire River Improvement Trust), Whitsunday River Improvement Trust and Upper Pioneer River Improvement Trust.

Contributions from other industry and community groups, agencies, consultants and individuals who have assisted during the project, particularly ID & A Pty Ltd, McIntyre & Associates Pty Ltd, Ullman & Nolan Pty Ltd, Connell Wagner Pty Ltd, Lawson & Treloar Pty Ltd and Cairns Port Authority, are gratefully acknowledged.

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The authors also acknowledge the input of other researchers from the School of Engineering, the Australian Centre for Tropical Freshwater Research, and the School of Tropical Environment Studies and Geography at James Cook University who have participated in the research, namely Prof. Ray Volker, Dr Paul Clayton, Mr George Lukacs, Mr Morgan Thomas, Mr John Lowry and Dr Mark Mabin. Ms Annika Persson prepared many of the diagrams. Project Director for the work was Prof. Archie Johnston.

Lastly, we thank the reviewers of the document (John Amprimo, Peter Bratt, Des Chalmers, Robert Ellison, John Gardiner, Peter Gilbey, Lyall Hinrichsen, Ross Hogan, Rob Hunt, Steve Kelly, Andy Markham, Simon O'Donnell, Grant Paterson, Phil Price, Ian Rutherfurd, John Tilleard and Sue Vize) for their valuable contribution to ensuring that the outcome is robust and will help practitioners follow improved practices for stabilisation and rehabilitation of streams in north-east Queensland.

Photographs in this document have been provided by Robyn Barnard, Mark Crees, Lyall Hinrichsen, Ross Kapitzke, Richard Pearson, Alan Pomeroy, Leonard Sands, Steve Skull and Walter Wilcox. Aerial photographs reproduced with permission by Department of Natural Resources, Queensland.

Disclaimer

Stream Stabilisation for Rehabilitation has been prepared from existing technical material, from research and development studies and from specialist input by researchers, practitioners and managers. The material presented cannot fully represent conditions that may be encountered for any particular project. The authors and sponsoring organisations have endeavoured to verify that the methods and recommendations contained are appropriate to north-east Queensland. The document does not contain a comprehensive statement of the legal obligations, including the legal obligations applying to concerned parties, and readers should seek legal advice before acting upon the recommendations. The document does not provide detailed financial advice and readers should obtain professional financial advice prior to effecting any of the recommendations.

Stream Stabilisation for Rehabilitation is not intended to be a code or design standard. Users should make their own site-specific evaluation, and testing and design arrangements, and should obtain their own specialist advice and input. Use of the guidelines requires professional interpretation and judgement, and appropriate design procedures and assessment must be applied to suit the particular circumstances under consideration. The adoption of these guidelines will not necessarily guarantee compliance with any statutory obligations, with the stability of any stream, structure or treatment; with enhanced environmental performance; or with avoidance of environmental harm or nuisance.

The authors and sponsoring organisations of this publication accept no liability or responsibility for the user, any other person or entity who suffers any loss or damage caused, directly or indirectly, by their adoption and use of the methods and recommendations of the guidelines. This shall include, but not be limited to, any interruption of service, loss of business (including any anticipatory profits) or consequential damages.

Chapter 1 - Concepts, Principles and Practices

Summary

- The coastal streams of north-east Queensland are important for human use and are a vital component of natural ecosystems. Human activity has placed direct and indirect pressures on the streams, leading to problems which have affected both human utility and ecosystem functions.
- Stream managers have traditionally emphasised flood and erosion control and adopted 'hard' engineering solutions for stream management problems. Such an approach ignores the dynamic nature of streams and, in many cases, has exacerbated rather than solved the problems.
- This document focuses on stream stabilisation and rehabilitation, which are mutually-dependent aspects of an integrated approach to stream management that considers human use and natural function of the stream.
- Good stream management incorporates not only reactive recurrent activities that respond to existing or emerging problems, but also proactive strategic activities aimed at long-term solutions to possible future problems.
- Stream stabilisation and rehabilitation projects at various sites on the stream need to be undertaken within the context of a management plan for the stream reach and a strategic plan for the stream catchment.
- This document provides for the planning, design and implementation of specific projects at the site/reach scale and for long-term programs of work at a broader catchment scale.
- Stream managers should follow the procedures and principles presented in this document for all projects, simplifying them as necessary for less complex problems.
- Improved, cost-effective outcomes for remediation programs will result when stream managers understand stream processes and the effects of human use, and address the causes of stream management problems.

1.1 Introduction

Purpose

This publication:

- provides a basis for users to improve the planning, design and implementation of environmentally-sensitive stream stabilisation and rehabilitation practices in the coastal areas of north-east Queensland;
- presents a philosophical approach to stream stabilisation and rehabilitation that acknowledges the value of streams for humans and as natural ecosystems;
- provides a framework within which a trained professional (eg. engineer, environmental scientist, ecologist, geomorphologist), with specialist input as required, can undertake a stream stabilisation and rehabilitation project; and
- is a reference document for policy makers, management and regulatory agency staff, consultants, researchers, trainers, educators, students, contractors, landowners and others involved in sustainable stream management.

Throughout, the document emphasises ten guiding principles for stream stabilisation and rehabilitation in north-east Queensland coastal streams (Box 1.1).

This document uses a practical approach to implementing scientific principles. It aims to guide users away from more traditional, but often inappropriate, approaches and away from reliance solely on trial and error. It also takes the pragmatic view that decisions need to be made even when the understanding of stream processes and treatment performance is less than perfect, and that, in some situations, conflicts between objectives may not be able to be resolved without compromise solutions.

Stream stabilisation is an important component of stream rehabilitation, which is a form of stream restoration. Stabilisation refers to methods for treating unstable physical systems. Rehabilitation improves the physical and biological condition of a degraded stream. Restoration is concerned with all aspects of returning the stream to a naturally-functioning system.

Context

The coastal streams of north-east Queensland, like streams elsewhere, have both ecological *and* utilitarian values. Human activities in the catchment, on the floodplain and in the stream itself have affected the physical and biological condition of many of the streams, some of which link two World Heritage listed ecosystems, the Wet Tropics rainforest and the Great Barrier Reef.

Catchment-wide strategic planning, stream condition surveys and catchment rehabilitation plans have provided inventories and a strategic direction for rehabilitation and management of many streams. Nevertheless, a lack of information about stream behaviour in tropical regions and a shortage of stream process and case study performance data for north-east Queensland have meant that stream management practices and stabilisation and rehabilitation techniques often rely on inappropriate and unsustainable adaptations of techniques from other regions. Furthermore, stream management approaches should now be based on the principles of sustainable development and integrated catchment management, and should therefore encompass stream rehabilitation - not merely stabilisation. The research and development on which this publication is based was designed to address this lack of information and develop an appropriate approach for the region.

Box 1.1 Ten Guiding Principles for Stream Stabilisation and Rehabilitation

Because of the variety of conditions and circumstances encountered, detailed prescriptive guidance on stream stabilisation and rehabilitation in north-east Queensland coastal streams is neither achievable nor appropriate. However, some basic principles should generally be applied. The principles presented below do not replace the requirement for detailed investigations, planning and design outlined elsewhere in this document, but they do represent the themes that run through it.

Principle	Requirements
Sustainability	Provide for long-term ecological functions and utilitarian requirements of streams by mitigating the impacts of new developments and rehabilitating degraded systems.
Multiple Objectives	Adopt multiple objectives which recognise both the natural functions and the human uses of streams, and which incorporate ecological, aesthetic and cultural values.
Intervention and Natural Recovery	Combine intervention with natural recovery. This approach is more likely to be appropriate to sustainable stream management than are policies of absolute control or abandonment to complete naturalness.
Catchment Context	Plan and implement projects in the context of both the site and the catchment, recognising the different influences and processes that occur at these different scales.
Stakeholder Consultation	Involve landholders, industry and community groups and government agencies in identifying problems, setting objectives, and determining appropriate stabilisation and rehabilitation treatment(s).
Strategic Approach	Aim to prevent or mitigate against problems before they become severe. Plan strategically and avoid short-term solutions.
Interdisciplinary Approach	Integrate hydrological, geomorphological, ecological and socio-economic considerations in planning and design.
Stream Management Expertise	Seek specialist advice, as appropriate, to ensure that the effects of natural stream processes are considered, and that the causes, not merely the symptoms, of the problems are addressed.
Planning, Design and Evaluation	Incorporate project phases that identify and examine issues, problems, processes, causes and objectives early in the project. Consider and evaluate options in increasing detail in successive project phases. On-going evaluation is a vital component of adaptive management.
Integrated Research and Development	Cultivate collaboration between managers, practitioners and researchers through integrated research and development, training and extension activities.

The background to this document

The research behind this publication focused on the wet tropics, dry tropics and moist tropical regions of north-east Queensland, from the Daintree River to the Pioneer River (Figure 1.1). Much of the information came from the 16 river basins that encompass the coastal streams of north-east Queensland. The research took an interdisciplinary approach, embracing the disciplines of engineering, ecology and geomorphology, and entailed:

- examination of stream management problems and causes, and the range of responses used;
- assessment of stream processes and environmental conditions;
- identification of the important geomorphological and hydrological processes that affect streambank instability;
- assessment of habitat changes associated with streambank instability and stabilisation works;
- evaluation of both conventional and ecologically-sensitive stream stabilisation strategies and treatments;
- case studies of treatments in coastal streams in the region; and
- development of a planning and design methodology for stream stabilisation and rehabilitation that accounts for physical, biological and socio-economic factors.

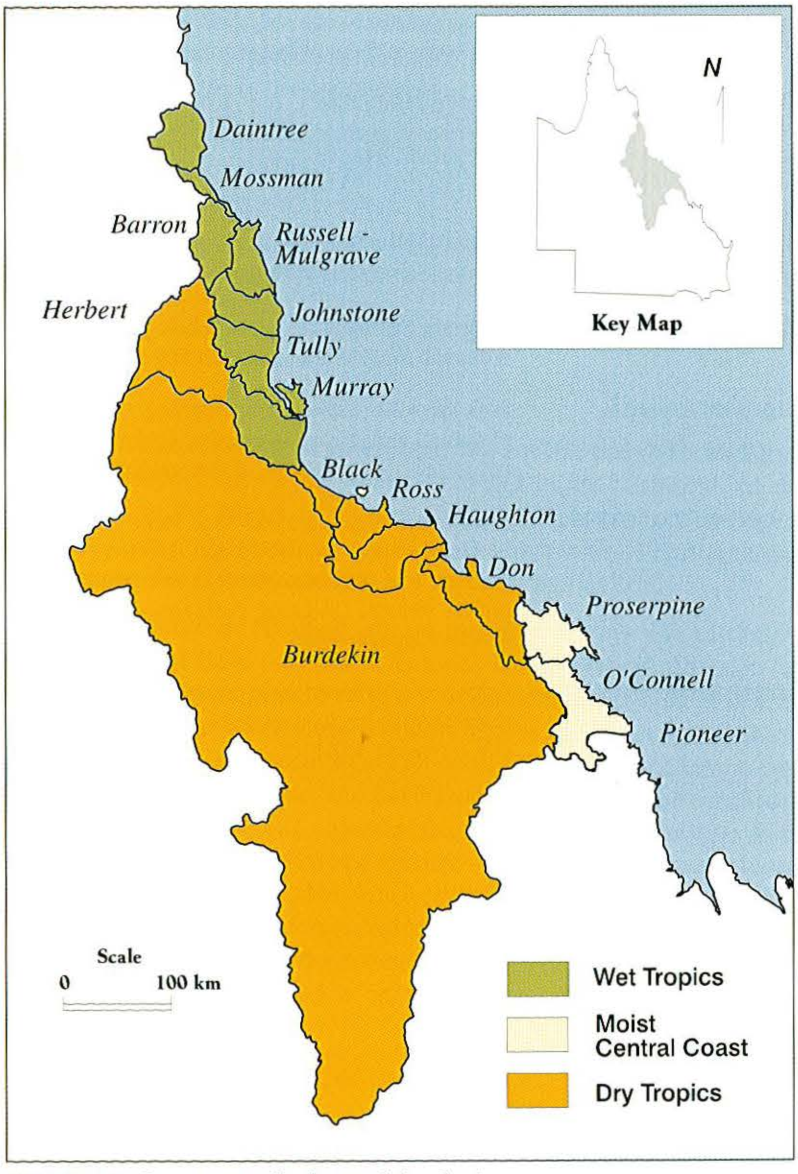

Figure 1.1 North-east Queensland coastal river basins

The scope of this document

The approaches and techniques presented here do not represent a design code requirement or standard. They complement, but do not substitute for, professional experience or professional judgement based on site-specific evaluation and design. Special site conditions may require more comprehensive treatments than indicated here. Streambank stabilisation and rehabilitation projects do not lend themselves to a cookbook type of approach, and the complexities of natural systems do not allow prescriptive methods to be set down.

This document helps readers to understand the causes of problems and to select and implement appropriate strategies and treatments. Users of this publication should have a basic understanding of stream systems. Previous specific experience in stream stabilisation or rehabilitation would be useful but is not essential. Because the approach draws on principles of engineering, ecology and geomorphology, individual users may require specialist input in areas outside their expertise.

The document provides for the planning, design and implementation of stream stabilisation and rehabilitation projects at the site/reach scale, and for long-term programs of work at a broader catchment scale. It emphasises the conceptual phase and feasibility evaluation of projects rather than detailed design.

Stream managers should follow the procedures and principles presented in this document for all projects, simplifying them as necessary for less complex problems.

The document does not include detailed procedures or values of parameters for such things as hydrologic and hydraulic analyses and structural design of stabilisation or rehabilitation works. Where appropriate, users are directed to the relevant literature for this detail.

The document does not attempt to assign unit costs to treatment types, labour, equipment or materials. This would not be feasible, as rates are site-specific.

Whilst the document has been developed for streams in coastal north-east Queensland, much of the material will also be relevant to other regions.

Lastly, this document does not claim to be exhaustive or final - it provides our present assessment of the preferred approaches to stream stabilisation and rehabilitation needs.

To make the document more readable, detailed referencing has not been used in the body of the text. However, Chapters include a list of recommended reading and the bibliography provides a full list of relevant references.

1.2 The Significance of Streams

Streams are critical elements of the natural environment. They contribute substantially to landscape form, and they provide essential drainage from catchments. Stream flow, erosion, sedimentation and transportation of debris are among the most potent natural physical processes, with the capacity to move vast quantities of material over large distances. With their adjoining floodplains, streams provide essential habitat for aquatic and terrestrial plants and animals. For humans, streams have environmental, political, social and economic values. They provide food, water, drainage, recreation, energy, fertile lands and a means of communication and transportation (Plate 1.1). They may also present problems by way of floods and erosion, and can be degraded both physically and biologically by human activity (Plate 1.2).

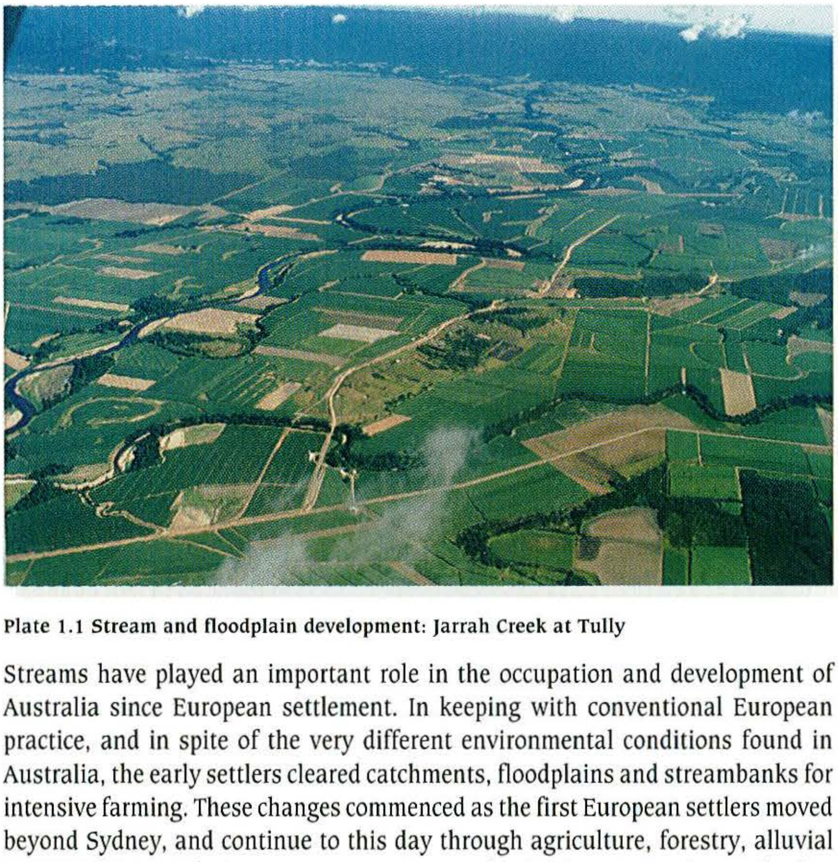

Plate 1.1 Stream and floodplain development: Jarrah Creek at Tully

Streams have played an important role in the occupation and development of Australia since European settlement. In keeping with conventional European practice, and in spite of the very different environmental conditions found in Australia, the early settlers cleared catchments, floodplains and streambanks for intensive farming. These changes commenced as the first European settlers moved beyond Sydney, and continue to this day through agriculture, forestry, alluvial mining, flow regulation, water extraction, urbanisation, recreation and other catchment modifications.

The Australian stream environment is characterised by highly variable hydrologic and climatic regimes, and shallow, poorly-developed soils. Much of the native aquatic biota is adapted to, and dependent on, these variable natural flow conditions, and is therefore affected when they change.

Whilst the impacts of some human activities are irreversible, many can be redressed by better protection of natural attributes, and by sustainable management of resources.

Changing attitudes towards streams

The community's perception of appropriate stream use is changing. Traditional European views, which emphasise the value of streams to humans, are progressively being modified. Stream managers, planners, politicians and the wider community increasingly recognise the ecological and landscape values of natural streams.

This recognition of the broad range of stream values is embodied in the principles of ecologically sustainable development. It is manifested in catchment-wide planning (integrated catchment management, or ICM) and in programs to improve the physical and biological health of the streams. In contrast to the previous approach of controlling stream behaviour, sustainable stream management attempts to reconcile immediate needs with long-term sustainabilty. This requires recognition and understanding of both the natural and utilitarian values of the streams.

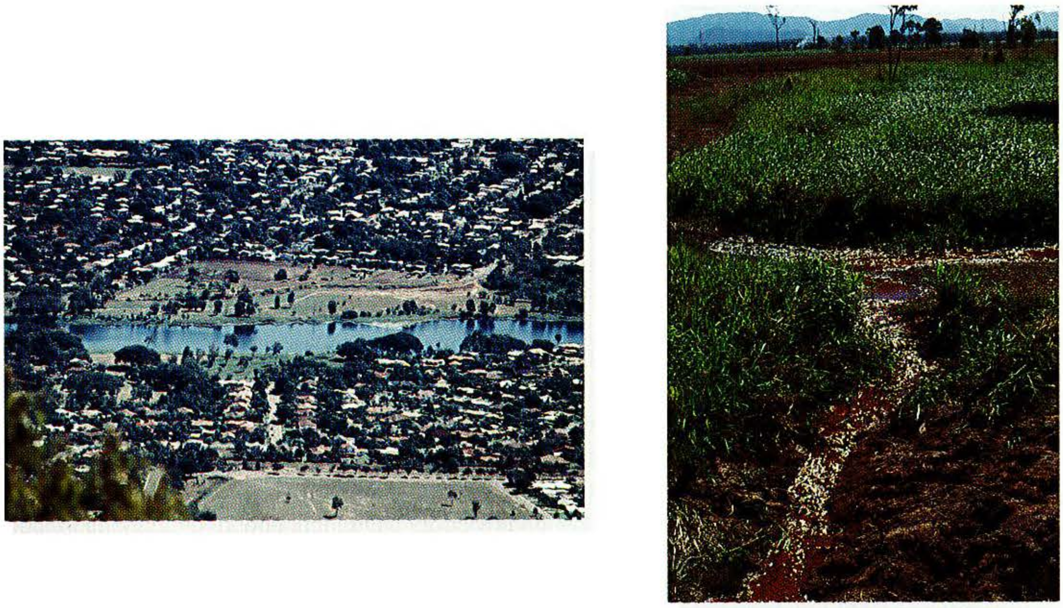

Plate 1.2 The effects of human development on streams: (a) Urban development in Townsville; (b) Degraded stream in agricultural area

Natural stream values

Streams provide primary habitats for animals and plants, continuous supply of essential nutrients and food, downstream transport of waste, and a means of physical and biological dispersal. Streams link terrestrial, freshwater and marine habitats, providing migratory pathways as well as a source of fresh water, nutrients and sediments to floodplain wetlands, estuaries and coastal marine waters. They play a major role in shaping landscapes, thereby promoting habitat diversity.

The riparian zone, where the terrestrial landscape comes into contact with the stream, protects the stream's physical condition and maintains the health of the associated aquatic and terrestrial ecosystems. Riparian vegetation provides shade, leaf litter and nutrients to streams, an avenue for plant and animal dispersal, and an important refuge for a wide diversity of wildlife. Conservation of streambank habitat in the riparian zone improves water quality and environmental conditions in and adjacent to the streams (Plate 1.3). A well-managed riparian zone enhances streambank stability, provides a nutrient and sediment filter between the stream and adjacent development, and provides a pool of predators which help control agricultural pests. In an urban environment, the riparian corridor offers recreational and aesthetic values.

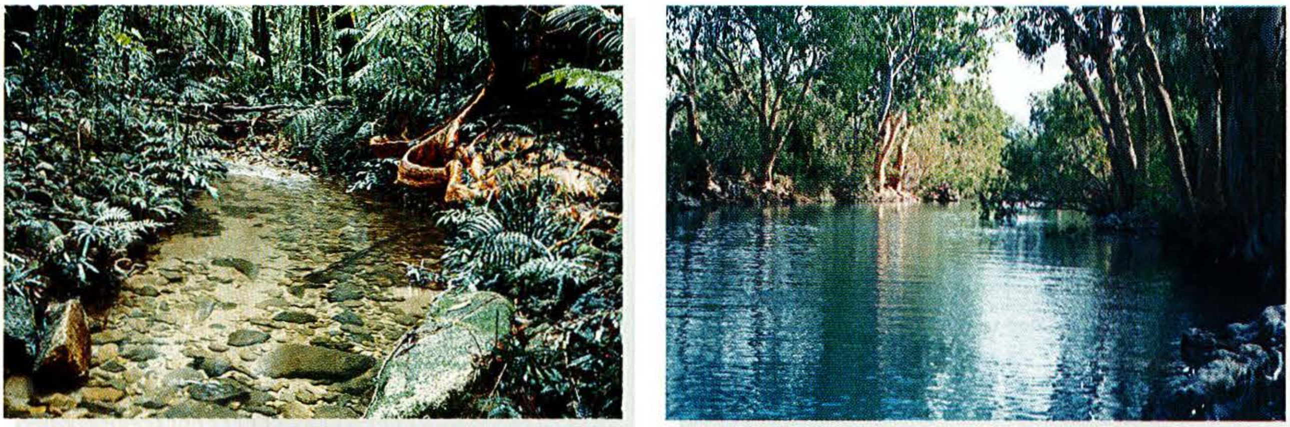

Plate 1.3 Natural stream and riparian zone: (a) Birthday Creek near Ingham; (b) Bluewater Creek near Townsville

Utilitarian stream values

Traditional uses of streams, such as water supply, drainage, fisheries, transport and hydro-electricity generation, have recently been supplemented by uses oriented more towards recreation and conservation. The various human uses of streams, and examples from north-east Queensland, are presented in Table 1.1, and illustrated in Plate 1.4.

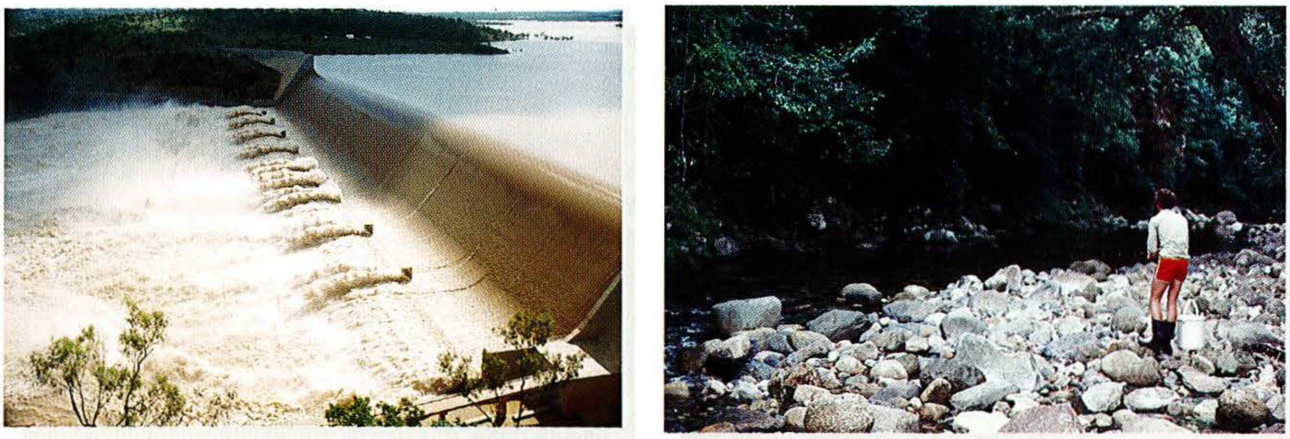

Plate 1.4 Human use of streams: (a) Water supply: Burdekin Falls Dam on the Burdekin River; (b) Recreational fishing

Table 1.1 How humans use streams

	Human use	Examples in north-east Queensland
Water supply	Water is supplied for urban, industrial and agricultural purposes from natural or regulated stream flows. Supply commonly involves flow regulation and storage structures such as dams, weirs and pumped diversions.	Urban water supply for Cairns is from a dam on Freshwater Creek; agricultural and industrial water is supplied to Burdekin delta and Townsville from Burdekin Falls Dam.
Hydro-electricity	Streams in mountainous, high rainfall areas are sometimes used to generate hydro-electricity. Dams are typically built in the headwaters, and downstream flows are diverted and regulated.	Hydro-electric power stations at Barron Falls and Kareeya are supplied from Tinaroo Falls Dam on the Barron River and Koombooloomba Dam on the Tully River.
Water conveyance	Stream channels are commonly used in a natural or modified form to convey water from storage sites to diversion sites - for example, from dams in the headwaters to weirs and pump stations on the floodplains.	Regulated flows from the Burdekin Falls Dam and Peter Faust Dam are conveyed down the Burdekin and Proserpine Rivers to weir and pump diversion sites.
Drainage	Streams provide natural drainage for runoff in their catchments. They may be modified to accelerate drainage from wetland and floodplain areas that have been developed for urban and agricultural uses.	All streams in the region retain their natural drainage function. Many have been modified and affected by accelerated runoff from catchment development.
Waste removal	Streams are sometimes used for residual drainage and removal of wastes. This may include point source discharges from industrial plants, and non-point source discharges from urban and agricultural runoff.	All streams in the region are subject to some form of waste discharge in developed areas. Elevated nutrient levels from agricultural areas may affect the Great Barrier Reef.
Transportation	Streams with adequate flow and waterway area have traditionally been used for transportation. Stream channels are often modified to improve navigation.	Apart from estuaries in urban areas, north-east Queensland streams are not extensively used for transportation because of their irregular flows and limited access.
Aggregate extraction	Sand and gravel deposits are extracted from many alluvial streams to supply aggregate for the building industry. Material may be taken from the bed or from point bar deposits.	Extraction occurs to varying extents in almost all streams in the region.
Fish resources	Streams provide a natural source of freshwater and marine fish, but resources may be affected by flow regulation, channel modifications, waste disposal and degradation of riparian habitat.	Freshwater fisheries are not extensive in the region, but commercial and recreational fisheries are significant in estuarine areas. Barramundi is a commercially important species.
Recreation	Streams are commonly used for fishing, boating, kayaking, rafting, swimming, picnicking, and nature appreciation.	Many headwater streams are popular for swimming and camping, and fishing and boating is popular in many lowland streams.
Conservation	Natural streams provide essential habitat for instream and terrestrial plants and animals, contributing to local biodiversity and maintenance of life-support systems.	Headwater streams are typically well preserved, particularly in World Heritage Areas. Conservation values have been severely degraded in lowland streams in developed areas.

1.3 Issues in Stream Management

Human Pressures

In line with the *State of the Environment Report for Australia* (Department of Environment 1996), this document uses the concept of pressures to describe human activities that affect the stream environment. Pressures are classified here as either 'direct' (activities occurring on the stream channels and adjoining riparian lands) or 'indirect' (activities occurring within the catchment but remote from the stream).

The various human pressures are described and illustrated in Appendix A, and summary descriptions and examples from within north-east Queensland are presented in Table 1.2. Several are illustrated in Plates 1.5 and 1.6. A number of pressures fall within both the direct and indirect categories but have been classified here on the basis of their primary influence.

Many of the pressures presented in Table 1.2 correspond to the human uses described earlier (eg. flow regulation, aggregate extraction and recreation are listed as both human uses and pressures). Flow regulation (a utility for generation of hydro-electricity, for example), also represents a pressure through its effects on recreational use for white water rafting and canoeing, and on water supply for irrigation.

Some human uses, such as water conveyance and rafting and kayaking, may not represent any significant pressures on the natural stream system, but may themselves be adversely affected by pressures such as road embankment infrastructure that encroaches on the stream channel.

Plate 1.5 **Direct pressures on streams: (a) Encroachment of agriculture: Herbert River Anabranch; (b) Channelisation: urban drain in Townsville**

Plate 1.6 **Indirect pressures on streams: (a) Overgrazing leading to erosion and sedimentation; (b) Intensive cane farming has the potential for increased sediment and nutrient runoff**

Table 1.2 Summary of direct and indirect pressures on streams (see Appendix A for details)

	Pressure	**Examples in north-east Queensland**
Direct Pressures		
Flow regulation, water storage and diversion	Dams, weirs and flow diversions, constructed for water supply, irrigation, hydro-electric power and flood control, modify the flow regime and detrimentally affect the physical and biological environment of the stream.	Ross River Dam on Ross River and Peter Faust Dam on Proserpine River were constructed for water supply and flood mitigation; extractions and diversions from streams in Wet Tropics World Heritage Area.
Channelisation	Channel straightening, enlargement and re-alignment for navigation, drainage and agricultural and urban development, increase flow velocities, accelerate erosion and have major ecological impacts (habitat destruction etc.).	Streams have been channelised for agriculture on Barron, Tully and Burdekin River floodplains; channelisation and diversion for urban development has occurred (eg. Cairns, Townsville, Mackay).
River works	Bank stabilisation, alignment training, levee banks and stream clearing works, undertaken for erosion and flood control, may *increase* erosion, change flood patterns and degrade instream and riparian habitats.	Extensive rock revetment bank stabilisation works exist on the Burdekin and lower Pioneer rivers; levees alter flood outflows on the Tully and Haughton rivers; channels have been cleared on coastal streams.
Aggregate extraction and mining	Sand and gravel deposits extracted by excavation and dredging may cause physical and biological damage to the stream through bed and bank erosion and habitat degradation.	A high demand for sand and gravel from streams exists from the Daintree to Pioneer Rivers; stream instability problems resulting from extraction occur in the Black and Gregory Rivers.
Encroachment from agriculture, urbanisation and infrastructure	Urban and agricultural developments and road and bridge infrastructure can cause erosion, degrade riparian habitat and reduce water quality, recreation and conservation values.	Riparian land has been cleared for agriculture and grazing from the Daintree to the Pioneer River; urban and industrial encroachment occurs on the Johnstone, Ross, Proserpine and Pioneer Rivers
Recreation and boating	Recreation facilities such as camping areas and parks may cause erosion and degrade habitat. Boating may affect water quality and cause bank erosion due to wave wash, and may also interfere with biota.	Picnic and camping facilities exist on many streams from Daintree to Pioneer; bank erosion due to tourist boat wash occurs on coastal waterways (eg. Daintree River).
Introduction of feral animals, exotic fish and plant species	Exotic species of plants and animals may be introduced by agriculture, urbanisation and recreation activities. Infestation usually leads to degraded instream and riparian habitats, bank erosion and degraded water quality.	Woody weeds infest banks of the Burdekin and Don Rivers; aquatic plants choke waterways; feral pigs disturb banks; and exotic fish infest waterways in Wet Tropics streams.
Indirect Pressures		
Modified water and sediment flow regimes from catchment	Catchment landuse activities such as agriculture, forestry and urbanisation are accompanied by clearing of vegetation and changes in landform and drainage, leading to increased erosion and changes to water and sediment runoff regimes.	Coastal floodplains from the Daintree to Pioneer Rivers have been extensively cleared, with drainage modifications and wetland reclamations for agriculture and urbanisation; cattle graze around the Burdekin and Don Rivers.
Pollution with organic matter, biocides, heavy metals, nutrients and rubbish	Diffuse runoff and point-source discharges from agricultural, urban and industrial development pollute the streams. Sediments, nutrients and other pollutants may affect the physical and biological function of the stream and downstream areas.	Fertiliser runoff from agriculture, effluent from feedlots, and discharges from sewage treatment plants and sugar mills in coastal streams occur widely; industrial and commercial waste is discharged in Ross Creek.

Stream management problems

Stream management problems commonly arise when there is a conflict between a stream's natural physical and ecological functions and its use by humans. The links between pressures, utilities, stream processes and problems are shown in Figure 1.2.

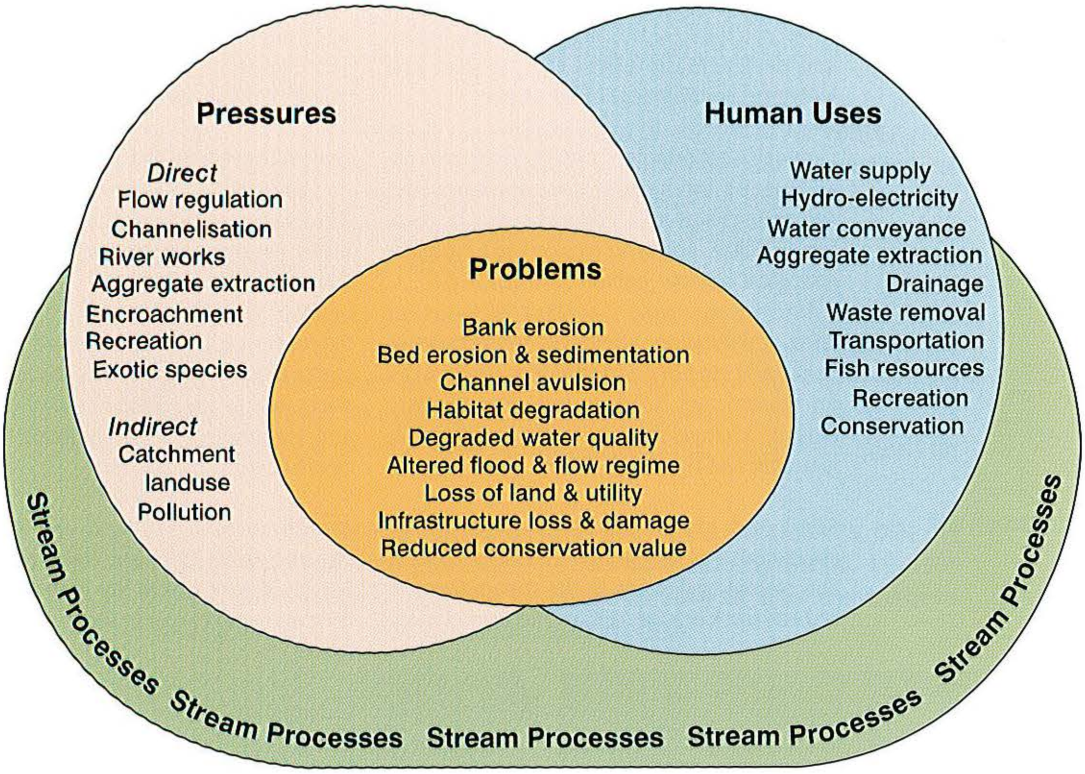

Figure 1.2 Human interactions with streams showing how uses and pressures can lead to problems

Stream management problems may arise where:

- human use leads to pressures (eg. flow regulation, encroachment) on natural stream processes (eg. physical form, hydrological patterns and stream habitats);
- natural stream processes (eg. flooding, erosion, sedimentation and stream course changes) impinge on human uses (eg. water supply, agricultural landuse and infrastructure); and/or
- natural stream processes (eg. flooding, erosion) accelerated by human pressures (eg. encroachment and catchment landuse) impinge on human uses (eg. water supply and infrastructure).

Streambank instability (the major focus of this publication) is only one type of stream management problem. Other problems that may occur include instream and riparian habitat degradation, degraded water quality, and damage to infrastructure. The various problems are described and illustrated in Appendix B, and summary descriptions and examples from within north-east Queensland are presented in Table 1.3. Plate 1.7 shows some examples.

Some problems may result from a combination of other problems. For example, channel avulsion and sedimentation may cause loss of land and damage to infrastructure; bank erosion and habitat degradation will usually reduce recreation value. Responses to problems such as streambank instability should consider

Plate 1.7 Stream management problems:
(a) Bank erosion and degraded habitat: Flaggy Rock Creek near Mackay;
(b) Sedimentation and habitat degradation: Babinda Creek at Babinda;
(c) Habitat and water quality degradation
(d) Reduced conservation and recreation value: Ross River, Townsville

other associated problems such as habitat degradation, loss of utility and reduced recreation value, because the various problems may have the same cause. Addressing this cause may therefore solve a number of problems. Furthermore, an integrated solution that addresses a number of causes may be necessary to solve a problem that stems from a number of other problems. This is the approach taken in Chapter 3.

Stream management problems may result from natural processes or from human-induced pressures. Identifying whether the pressures are direct or indirect is useful in determining responses to particular problems. Where the problems are related to direct pressures, a local response may suffice. For problems related to indirect pressures, the response will need to be catchment-based.

Indications of the likelihood of pressures leading to problems are set out in Table 1.4.

Table 1.3 Summary of stream management problems (see Appendix B for details)

	Problem	Examples in north-east Queensland
Fluvial bank erosion - scour	Soils are vulnerable on banks with degraded vegetation, exposed to high velocity and/or turbulent flow or boat waves.	Common on coastal floodplain streams from Daintree to Pioneer Rivers; particularly on outside of bends with already degraded riparian vegetation.
Mass movement - slumping	Silty or sandy soils may slump on banks subject to severe subsurface water and stream drawdown conditions and where vegetation is degraded. Cohesive material is more prone to slumping than are sands or silts.	Common following flooding in larger streams such as the Burdekin, Herbert and Pioneer Rivers.
Overbank erosion	Caused by flood flows out of or into the stream, usually where streambanks and riparian lands are degraded.	Common in streams with downstream-decreasing channel capacity and distributary flows (eg. Herbert, Haughton, Burdekin, Don and Proserpine Rivers).
Bed erosion	Scouring due to high velocity and turbulence, or headward erosion due to adjustments in bed gradient. Channelisation and sediment extraction are common causes.	Not common on the coastal floodplains, except at bridges and other structures; gully erosion occurs in upland areas such as the Atherton Tableland.
Sedimentation	Results from a decrease in stream transport capacity due to a local decrease in gradient or flow, or due to an increase in sediment load.	Common in lowland streams from the Daintree to Pioneer Rivers, particularly in the estuary reaches; instream vegetation often grows and flooding is more severe.
Channel avulsion	Stream leaves its course to form a new channel across the floodplain; usually occurs suddenly following gradual changes in stream morphology and flow regime, or may result from disturbance to the streambank.	Threat of major course changes in the Herbert, Haughton, Proserpine and Burdekin Rivers. Channel cutoffs are imminent on the Daintree, South Johnstone and Herbert Rivers.
Riparian habitat degradation	Changes to streambank morphology and reduction in riparian habitat values commonly result from encroachment, modifications to banks, poor stock management or introduction of exotic species.	Ubiquitous on lowland streams from the Daintree to Pioneer Rivers. Streambanks are altered and riparian vegetation width and integrity is severely reduced.
Instream habitat degradation	Changes to bed and bank morphology and reduction in instream habitat values commonly result from landuse change, channelisation, aggregate extraction or introduction of exotics.	Severe sedimentation and invasion of exotic grasses apparent in many lowland streams. Bed morphology is affected by aggregate extraction in the Mulgrave and Gregory Rivers.
Degraded water quality	Contaminants such as organic matter, biocides, suspended solids, heavy metals and nutrients may be introduced from urban, agricultural and industrial activities.	Nutrient, sediment and chemical loadings are elevated in many lowland streams; there is concern about transfer of sediments and nutrients to the Great Barrier Reef.
Altered flood and flow regime	Changes in the frequency, magnitude and duration of flood events, and changes to the low flow regime resulting from catchment and channel modifications and flow regulation (eg. dams, weirs and water abstraction).	Dams constructed on the Barron, Burdekin and Proserpine Rivers have altered downstream flood and flow regimes; there is concern about the effects on instream fauna and about the growth of vegetation in the stream.
Loss of land and utility, infrastructure loss and damage	Streambank erosion and channel avulsion cause loss of land and utility, and damage or loss of infrastructure. Sedimentation may cause loss of utility for navigation.	Loss of agricultural land and crops, and damage to farm infrastructure is common from the Daintree to Pioneer Rivers. Flood overflows and channel avulsions damage infrastructure on the floodplain.
Reduced recreational value	Restricted access, degraded swimming facilities and reduced aesthetic values may result from encroachment, exotic species and pollution.	Recreation values are affected on most lowland streams from the Daintree to Pioneer Rivers due to riparian and instream habitat degradation and degraded water quality.
Reduced conservation value	Degradation of natural stream processes, habitats and species composition of communities commonly result from flow regulation, encroachment and exotics.	Conservation values are affected on most lowland streams from the Daintree to Pioneer Rivers due to riparian and instream habitat degradation and degraded water quality.

Table 1.4 Relationship between stream management problems and pressures
Legend: (1) very unlikely; (2) unlikely; (3) possible; (4) likely; (5) always

Ratings provide a relative measure of the likely relationships between individual problems and pressures; they are not intended for quantitative use. Ratings were developed by a multi-disciplinary team.

Problems are usually expected at, or downstream of, the pressure on the stream, but may occur upstream (e.g. overbank flow or habitat degradation upstream of a weir).

	Direct Pressures (refer Appendix A for description)						Indirect Pressures (App A)	
Problems (refer Appendix B for description)	**Flow Regulation, Water Storage and Diversion**	**Channelisation & River Works**	**Aggregate Extraction & Mining**	**Encroachment from Agriculture, Urbanisation & Infrastructure**	**Recreation & Boating**	**Introduction of Feral Animals, Exotic Fish & Plant Species**	**Modified Water & Sediment Flow Regimes from Catchment**	**Pollution with Organic Matter, Biocides, Heavy Metals & Nutrients**
Streambank & Streambed Instability								
Fluvial bank erosion (scour)	3	3	3	4	4	3	4	1
Mass movement (slumping)	3	2	3	4	3	3	3	1
Overbank erosion	2	3	2	4	3	3	3	1
Bed erosion & sedimentation	4	4	5	3	3	3	4	2
Channel avulsion	1	3	2	3	2	3	3	1
Riparian Habitat Degradation								
Bank morphology	3	4	3	4	3	4	3	1
Riparian vegetation & fauna	4	4	3	5	4	5	3	4
Instream Habitat Degradation								
Bed & bank morphology	4	4	4	3	3	3	4	2
Instream vegetation & fauna	4	4	4	4	4	5	4	4
Water Quality & Flow Regime								
Degraded water quality	4	3	4	4	4	4	4	5
Altered flood & flow regime	4	3	3	3	2	3	4	1
Socio – Economic Factors								
Loss of land & utility	3	3	3	4	3	4	4	3
Infrastructure loss & damage	1	3	3	3	2	2	3	3
Reduced recreation value	3	3	4	4	3	4	4	4
Reduced conservation value	4	4	4	5	4	5	4	5

1.4 Stream Management Objectives

Around the world, stream management objectives are evolving from those aimed purely at protecting land and infrastructure and improving stream usefulness for human activities, to those seeking a sustainable balance between human requirements and natural stream function.

The traditional stream management activities related to flood and erosion control often aimed to control stream behaviour and fix stream geometry at specific locations, using protective materials such as rock (Plate 1.8). These approaches are no longer appropriate for all situations, and stream managers are increasingly aware of the benefits of understanding geomorphic and ecological stream processes and working with streams, rather than against them. This introduces objectives for improved physical and biological condition of the stream, not only stability for human use.

Plate 1.8 Traditional hard engineering in streams: Rock revetment on the Burdekin River

Contemporary stream management approaches consider both physical and ecological repercussions of activities, and recognise the links between streams and their catchments. Stream management objectives now include the maintenance and rehabilitation of water quality and riparian and instream habitat values, and improved recreation and conservation values (Plate 1.9).

Plate 1.9 Ecologically-sensitive stream management approaches:
(a) Timber pile groyne on the Mulgrave River; (b) Revegetation on Cleminson Creek at Malanda

The most advanced steps in the progression towards sustainable stream management are being made in the restoration of degraded streams to a condition that approximates the pre-disturbance physical and ecological condition. Streams have an innate ability to recover after stress, but recovery may take an extremely long time, and the stream may never recover to a naturally-functioning system. Restoration stimulates and enhances the natural recovery process through management and manipulation of some combination of water quality, hydrology, aquatic habitat structure and riparian zones. For example, intervention may be necessary to remove exotic species (non-native plants and animals), and to re-introduce native species. Stream stabilisation activities are often an essential component of stream restoration.

Stream management objectives for stabilisation and rehabilitation are described in Chapter 3.

1.5 Stream Management Strategies and Treatments

Once the nature and cause of the stream management problem(s) have been determined, stream management strategies can be developed to meet the desired objectives. The full suite of stream management responses includes stream stabilisation, catchment management, stream restoration, flood mitigation or non-intervention strategies. These guidelines are concerned primarily with stream stabilisation for rehabilitation and, therefore, the information on appropriate strategies and treatments is restricted to the stabilisation and restoration strategies. The approach is always set in a catchment context, and non-intervention is a possible option.

Alternative stream management strategies and stream stabilisation treatments, and examples of their use in north-east Queensland are introduced below. Appendix C presents more detailed descriptions of the stabilisation treatments most commonly used in north-east Queensland. This listing is not exhaustive, and the absence of a particular treatment does not necessarily indicate that it is unsuitable for a particular application. The user is referred to the relevant literature for more detailed information related to design of the treatments, and for more comprehensive descriptions and characteristics of strategies and treatments not presented here.

No prescriptive method can be given for selecting the appropriate stream stabilisation strategies and treatments. Chapter 3 presents the recommended planning, design and implementation procedure. The user should refer to the Guiding Principles (page 3) and to the Best Practice Checklist (Appendix D). Indications of the likelihood of various strategies and treatments achieving stream management objectives are set out in Table 1.5.

A stream management problem will usually have several aspects, and a combination of management strategies and treatments may be required to meet desired objectives. Vegetation is likely to be a component of the solution to most stream management problems.

Revegetation Strategies

Revegetation strategies for the riparian zone aim to improve streambank stability, increase resistance to erosion, improve water quality through filtering of sediment and nutrient runoff, and improve habitat, conservation and aesthetic values. Although exotic species have sometimes been used for revegetation, this is not recommended.

If implemented properly, vegetation treatments can be very effective, but they must frequently be used in conjunction with other treatments (eg. retards or revetments). Vegetation is commonly used to enhance other strategies (eg. alignment training, bank protection and grade control). Ideally, vegetation will always be considered first and, where it is not appropriate as the primary treatment, will be used as an adjunct to other treatments.

A revegetation strategy may incorporate a number of treatments in addition to planting native vegetation. These may include weed eradication, exclusion of feral animals and stock, and supplementary planting.

Vegetation has been successfully used on north-east Queensland streams, particularly since the recently increased emphasis on catchment management strategies. Revegetation strategies are in place for the Barron, Johnstone, Tully and Pioneer River basins and other miscellaneous streams.

Table 1.5 Suitability of strategies and treatments to meet stream management objectives
Legend: (1) very unlikely; (2) unlikely; (3) possible; (4) likely; (5) always

Ratings provide a relative measure of the likely suitability of individual strategies and treatments to meet stream management objectives; they are not intended for quantitative use. Ratings were developed by a multi-disciplinary team. Suitabilities relate to the treatment site. Offsite effects of treatments should be evaluated (e.g. poorly planned rock revetment may transfer an erosion problem downstream). Combinations of strategies and treatments will often be required to meet desired objectives for a site (e.g. rock revetment and vegetation may be used in conjunction with a pile groyne structure). Vegetation should be considered as an adjunct to all treatments.

	Streambank Stabilisation Strategies / Treatments (refer Appendix C for description)														Other Strategies			
	Revegetation	Alignment Training				Bank Protection and Stabilisation					Grade Control		Channel Modifications		Non-Intervention	Catchment Management	Stream Restoration	Flood Mitigation
Objectives		Rock Groyne	Pile Groyne	Retard	Embayment	Rock Revetment	Rigid Revetment	Bank Batter & Berms	Sub-surface Drain	Chute or Spillway	Bed Chute	Drop Struct	Clear & Desnag	Excav., Chann. & Cutoff				
Physical - Control Streambank & Streambed Stability																		
Streambank erosion	4	3	3	3	3	4	4	3	3	3	3	3	2	3	3	4	4	3
Streambed erosion	3	1	1	2	2	1	1	1	1	1	4	4	1	1	3	4	4	3
Overbank erosion	4	2	2	2	2	3	3	1	1	4	1	1	2	2	3	4	4	4
Sedimentation	3	3	3	3	3	1	1	1	1	1	1	1	3	3	3	4	3	1
Channel avulsion	4	2	2	2	2	3	3	1	1	4	1	1	2	2	3	4	3	4
Ecological – Enhance Environmental Characteristics																		
Instream habitat	5	3	3	3	3	2	1	2	3	3	3	2	1	1	3	4	5	1
Riparian habitat	5	3	4	3	3	1	1	2	2	2	3	3	1	1	3	4	5	2
Water quality	5	3	3	3	3	3	2	3	2	2	3	3	2	2	3	5	5	3
Socio-economic – Enhance Human Utility																		
Waterway Conveyance	1	1	1	1	1	1	1	1	1	1	2	2	4	3	3	3	3	3
Protect land & utility	4	3	3	3	3	4	4	3	3	3	3	3	3	3	3	4	4	3
Protect infrastructure	3	3	3	3	3	4	4	2	3	2	3	3	2	2	1	3	3	3
Recreation value	4	2	1	1	1	1	2	2	1	1	1	1	1	1	3	4	4	2
Conservation value	5	2	3	3	2	2	1	1	1	1	2	1	1	1	3	4	5	1

Alignment Training Strategies

Alignment training strategies (Table 1.6) influence stream behaviour by selectively introducing resistance to parts of the channel, or by using hydraulic structures to alter the flow characteristics. The principal application of alignment training structures is in the control of meander processes, but they may also be an effective component of strategies designed to deal with other issues. Alignment training structures may be used to shift flows away from the toe of eroding banks; create new alignments for an eroding bank, bridge or some other fixed point or line; control the width of the stream at that location; and control channel form or induce channel deepening or constriction. Other strategies (such as bank protection (Table 1.7) and revegetation) are commonly integrated with alignment training treatments.

Table 1.6 Alternative treatments for alignment training strategy (see Appendix C for details)

Treatment	Description	Examples in north-east Queensland
Rock groynes	Impermeable barriers projecting from the stream bank into the stream, obstructing the stream flow adjacent to the bank; usually close to top of bank height; suited to deep-water situations.	Haughton River Mill Farm near Giru; miscellaneous structures on Mulgrave, Herbert and Burdekin Rivers
Pile groynes	Permeable structures projecting from the stream bank, increasing flow resistance and directing flow away from the bank; usually close to top of bank height; suited to deep water situations.	Mulgrave River Stewart Road; proposal for pile groynes on Russell River
Retards	Permeable structures projecting from the stream bank, increasing flow resistance; usually lower than top of bank height; suited to shallow-water situations.	O'Connell River downstream of Bruce Highway bridge
Embayments	Permeable structures used to reclaim part of an eroded stream by obstructing stream flow adjacent to the bank; usually comprise fences in a grid pattern.	Don River Webster Brown; Cattle Creek Harris; miscellaneous structures in Pioneer River and St Helens Creek
Fences	Low structure running parallel with the flow, used to direct streamflow along a new alignment away from eroding banks.	Not known to be used
Vanes	Series of structures placed in the channel, designed to direct the principal streamflow away from eroding banks and redistribute secondary currents to minimise erosion.	Not in use
Bendway weirs	Submerged structures placed on the stream bed on the outside of a bend, designed to maintain channel depth and redistribute secondary currents away from eroding banks.	Not in use

Bank Protection and Stabilisation Strategies

Bank protection strategies (Table 1.7) directly protect the surface of stream banks from fluvial erosion, while bank stabilisation strategies minimise the risk of mass movements by reducing the load on the bank, or by providing greater strength to resist failure. Many techniques actually perform both functions. Bank protection strategies that prevent removal of stabilising material from the toe of the bank are also effective in preventing mass failure by collapse. Bank protection strategies are also used on the top and slopes of stream banks to control erosion by overland flow (eg. spillways and bank chutes). The stabilisation strategies may increase stability of the bank material through surface or subsurface drainage that reduces water content, battering of the bank, incorporation of a stabilising medium, establishment of vegetation to bind the bank material, provision of bank support against mass failure, or removal of surcharge from the top of the bank. Revegetation is commonly used in conjunction with bank protection and stabilisation.

Table 1.7 Alternative treatments for bank protection and stabilisation strategy (see Appendix C for details)

Treatment	Description	Examples in north-east Queensland
Rock revetment	Rock armouring of the stream bank to protect against erosion and stabilise against slumping failure.	Barron River Airport Bend; Burdekin River Swindley; Don River Potts Bank; miscellaneous structures in most coastal streams
Rigid revetment	Inflexible and impermeable layer placed on stream banks to protect against erosion; commonly used in estuaries where navigation is common.	Pioneer River estuary; miscellaneous structures in estuaries and urban waterways (eg. Ross Creek)
Bank battering & berms	Re-profiling of stream banks to improve stability, allow construction access, and as a preparation for other stabilisation works.	Commonly used for preparation of placement of rock revetment and for revegetation.
Subsurface drainage	Perforated pipes or trenches installed in the stream bank to lower the water table, reduce subsurface pressures and reduce the potential for slumping failures.	Herbert River Anabranch Bube; miscellaneous other sites on the Herbert and Burdekin Rivers
Bank chute	Armouring of the top and inside of the stream bank to control erosion from inflow to the stream.	Commonly used on small streams, particularly at entry of table drains from roadways.
Spillway	Armouring of the top and outside of the stream bank to control erosion from flood outflow from the stream.	Haughton River Savorgnan, Pappalardo and Lyons; Herbert River Halifax Washaway; Don River Webster Brown; Proserpine River
Rock mattresses and gabions	Flexible rock-filled wire baskets used to stabilise the stream bank or provide protection against erosion on the stream bed and banks.	Rankin Creek and Barron River on Atherton Tableland; miscellaneous modified waterways.
Retaining wall or bulkhead	Impermeable vertical or near vertical structures; suited to estuaries and urban waterways.	Common in urban waterways and at road embankments.
Soil stabilisation	Streambank soils mixed with stabilising material such as cement or lime to increase stability and resistance to erosion.	Common in urban waterways and at road embankments.
Geosynthetics	Natural or synthetic fibre cloths placed on a stream bank, either as a filter under rockwork, as soil reinforcement, or as a mat to enhance vegetation growth.	Same use as vegetation stabiliser and as underlay for rock revetment.

Grade Control Strategies

Grade control treatments (Table 1.8) are used to dissipate energy in the stream and to prevent the upstream advance of channel deepening, and to control avulsive channel courses. This is commonly done by placing one or more structures in the stream bed to step the bed profile. Bed stabilisation by grade control is often an important prerequisite for overall stream stability. Grade control structures are also used in conjunction with other structures and vegetation to increase flow resistance, thereby dissipating energy. The long-term effectiveness of a series of grade control structures will often rely on growth of vegetation between the structures. The establishment of vegetation is often assisted by sediment deposition. An effective treatment of a grade control problem will often integrate several approaches and may incorporate other strategies (eg. bank protection and stabilisation).

Table 1.8 Alternative treatments for grade control strategy (see Appendix C for details)

Treatment	Description	Examples in north-east Queensland
Bed chute	Graded drops in the bed of small streams; usually armoured with rock and placed in straight sections of streams.	Outlets to culverts and at bridge crossings; extensive use in agricultural drains, particularly in irrigation areas.
Drop structure	Vertical or near vertical drops in the bed of small streams; usually constructed as rigid concrete structures or as rock gabions.	Commonly used in urban waterways.

Channel Modification Strategies

Channel modifications (Table 1.9) are used to alter the stream configuration by removing obstructions to stream flow (eg. build-up of bed material, aquatic vegetation and snags) or by adjusting the planform of the stream through cutoffs and channelisation. These strategies have been used traditionally in stream management to increase waterway conveyance, improve navigation, reduce overbank flooding and, in some cases, reduce bank erosion and sedimentation. Channel modifications can have a devastating effect on the instream and riparian environment and, although sometimes still used in the north-east Queensland region, are not recommended other than in carefully controlled situations where they may be used to reinstate physical channel form and accelerate recovery of a degraded stream.

Table 1.9 Alternative treatments for channel modification strategy

Treatment	Description	Examples in north-east Queensland
Clearing & desnagging	Cutting and removal of vegetation or snags from the stream bed or banks.	Traditional practice that has recently been used or proposed in Herbert, Burdekin and Proserpine Rivers.
Channel excavation	Excavations to remove or relocate bed material either to increase waterway conveyance, stabilise stream banks, or to provide resource material for industry.	Traditional practice that has recently been used in Mossman, Russell, Tully and Burdekin Rivers and other streams.
Channelisation	Realignment, straightening, widening, deepening and lining of waterways; common for agricultural and urban drainage.	Traditional practice that has recently been used in some urban and agricultural waterways.
Cutoffs	Stream diversion across meander bends.	Traditional practice that is not presently in use and is no longer encouraged.

Miscellaneous Strategies

Several other treatments which have been used to stabilise stream banks (not always successfully) are briefly described below in Table 1.10. The practice of dumping car bodies and other rubbish to protect banks is not appropriate for ecologically-sensitive stream stabilisation and should not be used.

Table 1.10 Miscellaneous stream stabilisation treatments

Treatment	Description	Examples in north-east Queensland
Remove surcharge	Relocating surcharge such as buildings or machinery away from the top of the bank to prevent slumping failure.	Common in miscellaneous streams.
Car bodies and rubbish	Waste material placed on stream banks with the intention of stabilising the bank and increasing resistance to erosion.	Traditional practice that is no longer encouraged.

Non-Intervention Strategies

A policy of non-intervention may be used in a situation where the apparent stream management problem is merely a natural process that is not affecting human utility (eg. bank erosion in a natural stream environment), or where natural stream processes are likely to rehabilitate the stream within an acceptable time period. In other situations, it may be more appropriate to relocate whatever is affected by the steam instability (eg. building or cultivation). Monitoring is an essential component of a non-intervention strategy. Non-intervention should always be considered as an option; the cost in loss of amenity being compared with the long-term cost of treatments.

Catchment Management

The integrated catchment management (ICM) strategy attempts to deal with the causes of the problems in the catchment before they contribute to problems in the stream. Land use is a common thread tying catchment-based strategies to the stream system, and most catchment strategies incorporate changes to land use and landuse practices. Practices such as changing from agriculture to forest, revegetation, reducing stocking rates, stock control, soil and water conservation and pollution control are often components of a successful ICM strategy. Strategies to address problems in the catchment should be implemented in conjunction with activities to address problems in the stream (eg. rehabilitation of degraded bed and banks caused by encroachment or gravel extraction).

Catchment management strategies are in place on many of the river basins in north-east Queensland (eg. Daintree, Barron, Mulgrave-Russell, Johnstone, Tully-Murray, Herbert and Pioneer Rivers).

Stream Restoration Strategies

Stream restoration strategies, which aim to restore the stream to a naturally-functioning system, have been discussed earlier. Bank stabilisation can be an important component of restoration.

Stream restoration has been recently promoted for agricultural and urban waterways, particularly those in the Wet Tropics where aquatic fauna are naturally prevalent.

Flood Mitigation Strategies

Flood mitigation strategies address flooding issues in urban and agricultural areas. They may involve structural works (eg. retention dams, stream diversions, levees and floodgates) or non-structural works (eg. rezoning, flood-proofing and insurance). Flood mitigation strategies often incorporate stream stabilisation (eg. bank stabilisation) but may adversely affect stream processes (eg. flood and flow regime) and may, thereby, counteract stream rehabilitation objectives.

Many flood mitigation schemes were considered for the larger streams in the region in the 1980s. This included proposals to rationalise artificial levee bank construction in the Tully, Herbert, Haughton, Don and Proserpine Rivers. Although very few broad-scale flood mitigation strategies have been implemented, many components such as floodgates, levees and detention storages have been constructed on various streams throughout the region. Notable flood mitigation schemes include the levee banks on the Pioneer River and the flood mitigation dam and levee banks on the Proserpine River.

1.6 Recommended Reading

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Chapter 2 - Characteristics of North-East Queensland Coastal Streams

Summary

- The majority of north-east Queensland coastal streams are, over most of their length, dynamic alluvial systems, able to adjust their slope, location on the floodplain, and cross-sectional form relatively quickly in response to (often human-induced) variations in sediment supply and sediment transporting capacity.
- Stream hydrology, geomorphology and ecology are diverse because of the diversity of climates and landforms within the region's three biogeographic zones (wet tropics, dry tropics and moist central coast).
- Geomorphic and hydrologic models of stream behaviour based on temperate regions in south-eastern Australia and the Northern Hemisphere are not directly applicable to north-east Queensland coastal streams.
- The region experiences some of the highest annual rainfall totals in Australia, although rainfall and stream hydrology display marked inter-annual, seasonal and spatial variations.
- Annual streamflow volumes and the percentages of rainfall converted to runoff vary greatly through the region, reflecting catchment area, annual rainfall and biogeographic zone.
- Streamflow volumes and peak instantaneous flood discharges for north-east Queensland streams display significant inter-annual variability compared with other Australian and global streams.
- Streams often rise and recede quickly in major floods.
- Stream channel capacities commonly decrease in the downstream direction in lower floodplain reaches, and overbank and distributary flood flows occur often.
- The landforms of the coastal plain are mostly depositional, with well-developed river meanders and levees, river terraces and backswamps, and complex estuarine systems.
- Alluvial floodplain streams are prone to channel changes as a result of bank erosion, channel incision or deepening and channel avulsion. These changes are accelerated by human activities.
- Streambank instabilities predominantly occur within silty sand and sandy silt deposits as fluvial erosion (scouring) and mass movement (slumping).

- The principal factors affecting scouring and slumping are stratigraphy, soil properties, vegetation, streamflow and stream modifications. Other significant factors are planform location (scouring) and subsurface drainage (slumping).
- Scouring and slumping are accelerated in agricultural and urban areas on lowland streams where riparian vegetation has been extensively cleared and remnants substantially degraded by infestation with exotic grasses.
- North-east Queensland streams support vital ecological processes in the landscape, including maintenance of biodiversity, pathways for migration between two World Heritage Areas, transport of organic material downstream and production of biological material which contributes to the terrestrial zone.
- The streams and riparian zones provide particularly diverse habitat, and consequently high floral and faunal diversity.
- The terrestrial part of the riparian zone typically includes unique plant species, especially trees and shrubs, which provide habitats for many unique terrestrial and semi-aquatic animal species.
- The riparian zone is especially important in agricultural areas because it provides habitat and a means of dispersal and migration for native species. A healthy riparian zone provides shade (which reduces stream temperature and growth of weeds) and input of leaf litter) a major source of organic material for the stream community).

2.1 Context

An understanding of catchment characteristics, stream processes and geomorphology is essential if the nature and underlying causes of stream management problems are to be recognised, and effective and appropriate stream management strategies are to be developed.

Regional Setting

This publication is based on information from the 16 coastal river basins between the Daintree in the north and the Pioneer in the south (Figure 1.1), which together cover more than 169,000km^2 and extend along more than 600km of the north-east Queensland coast. Climates and landforms within this region are diverse. Diversity of climate is related to variations in latitude, relief, and the orientation of the coastline relative to prevailing southeasterly winds. Landform diversity stems from the interaction of these climates with the varied geologies and geologic histories of the region.

Stream hydrology characteristics in the region usually reflect the catchment physiography and climate. Not surprisingly, given the variety of climate and landform within the study area, stream hydrology, geomorphology and ecology are diverse.

Stream Classification

The majority of streams within the region are, over most of their length, dynamic alluvial systems, able to adjust their longitudinal profile (slope), location on the floodplain (planform), and cross-sectional form (width/depth/shape) in response to variations in sediment supply and sediment-transporting capacity (streamflow). Such variations and adjustments may occur at a variety of spatial and temporal scales.

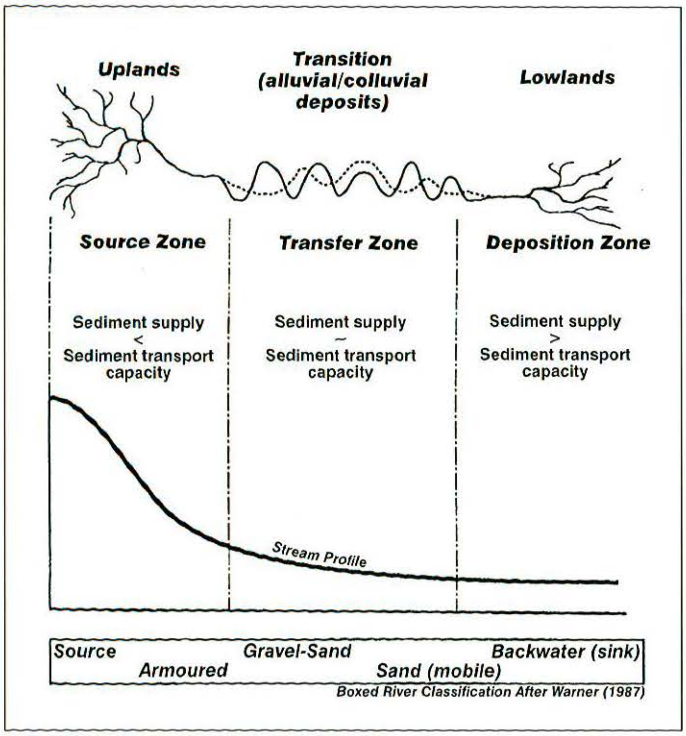
Simplified models of natural stream systems typically define three geomorphic zones. These are distinguished by the balance between sediment supply to the stream and the stream's sediment transport capacity (Figure 2.1).

Zone 1 is the sediment production or ***source zone***. It usually consists of steep upland areas which shed rather than store sediment. Landforms which store sediment (such as levees and alluvial flats) are typically absent from this zone because, in the long-term, the amount of sediment supplied from hillslopes is less than the stream can transport. As a result, all but very large material is carried away and streams in the source zone often flow on bedrock or over coarse bed material.

Downstream of the source zone is the sediment ***transfer zone***. Stream gradients decrease through this zone, and the stream often develops a meandering planform with point bars in the stream. In this zone the stream usually flows through an alluvial floodplain composed of sediments in transit or temporary storage. The movement of all but the finest sediment through this zone is typically intermittent, usually with short periods of transport and long periods of storage. Though adjustments of channel form result in some sediment being redistributed, there is no net erosion or deposition in the sediment transfer zones of stable streams.

The third zone is the sediment ***deposition zone***. Here, sediment supply exceeds the capacity of the stream to transport it further downstream. The deposition zone is a zone of long-term sediment storage, with sediments forming landforms such as levees, alluvial fans, deltas and coastal plains.

Classification into these three geomorphic zones provides a useful framework for considering hydrological processes (such as streamflow) and ecological processes



Boxed River Classification After Warner (1987)

Figure 2.1 Simplified stream system model (after Schumm, 1977) showing later divisions proposed by Warner (1987)

(such as the dynamics of organic material, food webs and responses to disturbances).

More detailed stream classifications exist. Some of these divide stream networks into progressively smaller, spatially-nested units (eg. stream segments, reaches and sites). Others incorporate direct mechanistic links between stream morphology and processes, and also consider the natural variability of the system in time as well as in space (eg. Nanson and Croke, 1992).

Timescales

Alluvial streams systematically adjust their morphology through time and space in response to disturbances, and it is possible to interpret present and future processes and geomorphic changes at a site by recognising a channel's 'stage of evolution'.

Natural processes of stream adjustment may occur at an imperceptibly slow pace, or they may occur suddenly and cause dramatic changes to the stream system (eg. as a result of landslip or catastrophic flooding). Catastrophic changes may be perceived as extremely damaging to stream condition from the perspective of a human lifetime. However, from a longer-term geologic perspective, such change may represent fluctuations about a more or less steady state in dynamic equilibrium.

When streams are monitored daily a ***static equilibrium*** between stream process and form is generally observed, with little if any noticeable change on a day-to-day basis (Figure 2.2a). The exception is during major erosion events.

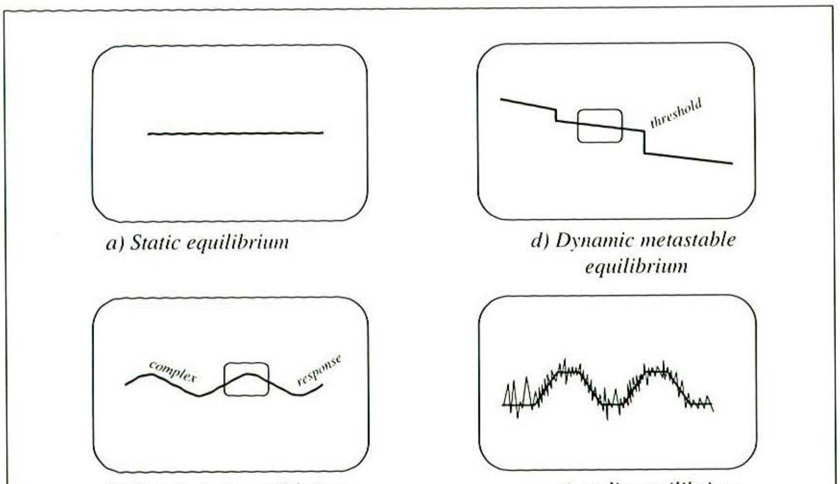
Changes in morphology are more conspicuous when streams are viewed over extended timescales (years to centuries), but these conspicuous changes are nonetheless usually random fluctuations about a longer-term average. Streams behaving in this fashion are said to be in a ***steady state equilibrium*** (Figure 2.2b). They are characterised by meanders which adjust their form in response to moderate and major floods and migrate across and down alluvial floodplains.

Over still longer timescales, progressive trends in the longer-term average form and/or position of the stream can be recognised. This is a state of ***dynamic***

equilibrium (Figure 2.2c). It is often possible to identify discrete episodes superimposed over this longer-term trend, during which relatively large adjustments were made over a relatively short time. This scenario of stream changes is known as a ***dynamic metastable*** or ***quasi-equilibrium*** (Figure 2.2d); it is influenced by thresholds that may be either within or external to the stream system (Section 2.4). Two additional equilibrium conditions have been suggested by Nanson and Erskine (1988) for coastal streams in New South Wales. One of these is ***cyclic equilibrium,*** in which a new equilibrium condition is approached between each threshold (Figure 2.2e), and the other is ***episodic disequilibrium***, in which a distinct equilibrium is not reached at any point, although the rate of change between each threshold is slower than at the threshold (Figure 2.2f).

Evidence suggests that oscillations about 'average' equilibrium positions and shifts to new ones occur over considerably shorter timescales in Australia than they do in the temperate settings where these models were developed. The hydrological characteristics of north-east Queensland coastal streams, particularly the strongly seasonal flows, high interannual flow variability, and large peak discharges (Section 2.3), suggest that the time periods over which these equilibrium models operate may be even shorter in the study region.

A particular challenge in developing sustainable stream management strategies is to recognise and accommodate the different timescales with which the various practitioners using these guidelines, and the affected communities are concerned. Relevant geomorphic processes occur at timescales varying from seconds to millions of years, and progress at variable rather than constant rates. In comparison, riparian and floodplain ecology has important time frames as varied as the lifecycles of individual organisms (which may vary from days to centuries) and engineering is usually governed by the design-life of the structure to be installed (typically 50-100 years). The identification of appropriate management timeframes for north-east Queensland stream systems is especially difficult because baseline geomorphic and ecological data are scarce.



a) Static equilibrium

d) Dynamic metastable equilibrium

b) Steady state equilibrium

e) cyclic equilibrium

c) Dynamic equilibrium

f) Episodic disequilibrium

Figure 2.2 **Schematic representation of timescales relevant to stream geomorphology (Horizontal axis represents time, vertical axis represents change in channel parameter such as width or depth)**

2.2 Climate

Seasonal Variations

North-east Queensland's climate is monsoonal. Mild conditions prevail for most of the year, although the summer months (December to April) are typically hot (mean daily temperatures of 24-33°C), wet and humid. Winter temperatures typically range between 15°C and 30°C.

The movement of the Intertropical Convergence Zone (ITCZ) strongly influences the region's climate, driving a pronounced seasonal rainfall rhythm. In summer, a southward extension of the ITCZ reaches into northern Australia. This encourages the inflow of warm, moist air, which converges with cooler southern air masses to produce heavy rainfall. Increased convective activity and warmer sea surface temperatures during summer may generate tropical depressions. These may intensify into tropical cyclones capable of producing intense, heavy rainfalls and major flooding in coastal catchments.

During the winter months the ITCZ lies north of Australia, and the region's climate is dominated by the influence of a belt of anticyclones crossing the continent at about 30°S, and a prevalent high pressure ridge along the north-east Queensland coast. Inland areas are usually quite dry over winter, with little or no rain between April and September. Coastal areas, particularly north of Ingham and south of Proserpine, usually receive orographic rainfall during winter as the prevailing south-easterly trade winds blow over the coastal ranges. Upper level troughs, which usually develop from the remnants of cold fronts in the upper westerlies, occasionally deliver more general winter rainfall to the region.

Rainfall

The coastal river basins of north-east Queensland receive some of the highest annual rainfall totals in Australia, although rainfall in the region is characterised by marked spatial, seasonal and inter-annual variation. Most catchments in the wet tropics (north of Ingham) have average annual rainfall totals exceeding 2,000 mm, with annual totals greater than 4,000 mm not unusual (Table 2.1). Considerably less rain falls in the dry tropics catchments (Black, Ross, Haughton, Burdekin and Don), with average annual rainfall totals ranging between 1 510 mm (Black) and 640 mm (Burdekin). The most southerly catchments of the region (Proserpine, O'Connell and Pioneer) are comparatively moist. Regional variation in average annual rainfall largely reflects the influence of coastal orientation and topography. The wetter catchments in the north and south of the region generate high orographic rainfall because they are almost perpendicularly aligned to the prevailing south-easterlies and have steep ranges close to the coast. In comparison, the dry tropics coastline is almost parallel to the south-east trades, and ranges are discontinuous and of lower relief. A sharp isohyetal gradient, related to topography, occurs throughout most of the region, with high and rapidly increasing rainfall totals occurring over the coastal plain to the crest of the coastal ranges, and totals declining westward due to rainshadow effects (Figure 2.3).

Table 2.1 North-east Queensland coastal river basin rainfall and runoff data

River Basin	Area (km^2)	Mean Annual Rainfall (mm)	Mean Annual Runoff Volume (1000 ML)	Runoff Depth/ Rainfall (%)
Wet Tropics				
Daintree	2 125	2 576	3 560	65
Mossman	490	2 459	687	57
Barron	2 175	1 447	1 153	37
Mulgrave - Russell	2 020	3 233	4 193	64
Johnstone	2 330	3 405	4 698	59
Tully	1 685	2 970	3 683	74
Murray	1 140	2 485	1 628	57
Herbert	10 130	1 331	4 991	37
Dry Tropics				
Black	1 075	1 510	509	31
Ross	1 815	1 071	372	19
Haughton	3 650	923	756	22
Burdekin	129 860	640	10 100	12
Don	3 885	1 022	689	17
Moist Central Coast				
Proserpine	2 485	1 562	1 431	37
O'Connell	2 435	1 705	1 668	40
Pioneer	1 490	1 418	994	47

(after Hausler 1990)

In the wet tropics, usually more than 60% of annual rainfall falls over summer. Generally, the most intense rains fall between December and early April in association with monsoonal lows and tropical cyclones. Rainfall intensities for one-hour duration storms can, on average, be expected to exceed 80 and 125 mm/hr every 10 and 100 years respectively. The most intense 24-hour rainfall in Australia (1 140 mm), and the highest 8-day rainfall intensity anywhere in the world (3 847 mm) were recorded at Bellenden Ker in the wet tropics (Hausler, 1990). Winter rainfalls associated with the orographic uplift of onshore winds or upper level troughs are much less intense, although daily totals of greater than 100 mm occasionally occur on the coastal plain.

The region is also characterised by marked interannual variation in rainfall totals which has been linked to the El Nino - Southern Oscillation (ENSO) phenomenon (eg. Glantz *et al.* 1991). Sea surface temperatures off the north-east Queensland coast are below average during El Nino years (represented by negative Southern Oscillation Indices). This reduces convective monsoonal and cyclonic rainfall over the region, and lowers orographic rainfalls (because the south-easterly trades weaken and deliver drier air to the coast). The dry tropics are subject to the most strongly seasonal rainfalls and have the least reliable wet seasons. For example, Hopley (1982) calculated that the annual rainfall variability index (standard deviation/mean multiplied by 100) for dry tropical catchments near Townsville was 57% compared with approximately 35% to 40% near Innisfail in the wet tropics. It is not uncommon for drought years to be interspersed with years of intense or higher than average rainfall. Not only are the annual rainfall totals highly variable between years, but also the onset and duration of the wet season rains vary markedly from year to year. Seasons producing early rains in December often fail to deliver average rainfalls in February to April.

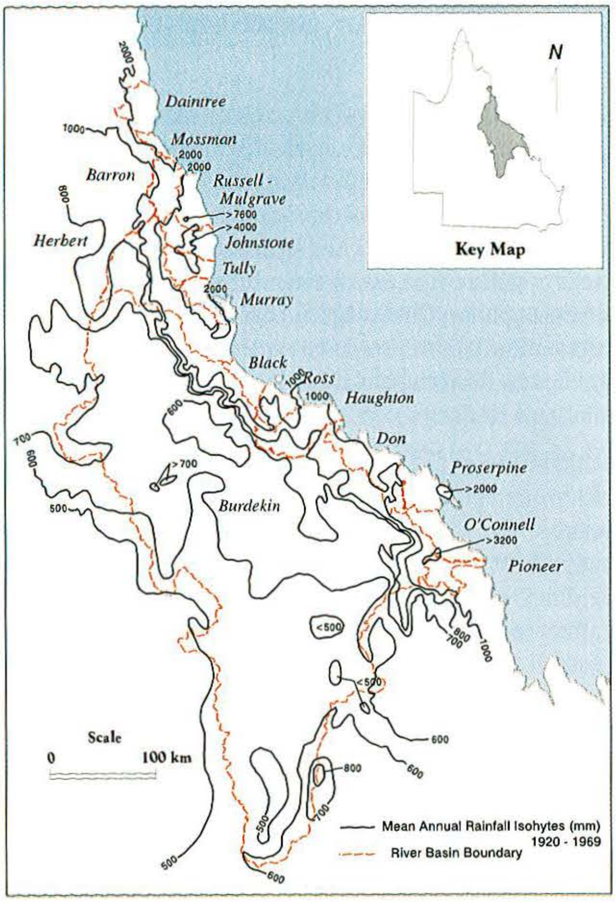


Figure 2.3 North-east Queensland coastal river basin (Daintree to Pioneer) mean annual rainfall isohyets

Cyclones

Tropical cyclones are a significant climatic feature of the north-east Queensland coastal region over summer, particularly between December and March. Tropical cyclones can produce large and intense rainfalls and cause major flooding. Flood rains may be produced by the active cyclone before it crosses the coast, or else they may occur as cyclones degenerate into tropical depressions inland. Records suggest that there is an approximately 50% chance of at least one cyclone crossing the coast between Mossman and Mackay each year (Hausler, 1990). Recent cyclones experienced in the region include Winifred (1986), Charlie (1988), Aivu (1989), Ivor (1990), Joy (1990-91), Violet (1995) and Justin (1997).

2.3 Hydrology

How streams influence human activities such as water supply and urban and agricultural floodplain development, and how they respond to human disturbances such as instream mining and flow regulation, can all be measured in terms of their hydrological characteristics. Stream hydrology directly affects the stability of the streambank and streambed and instream and riparian habitat conditions and, therefore, has a major influence on stream stabilisation and rehabilitation. Important hydrological characteristics include interannual variations in streamflow volume, seasonal streamflow patterns, the magnitude and frequency of floods, flood rise and recession rates, flood durations, and flood height and inundation characteristics of the stream and adjoining floodplain.

As the driest inhabited continent on earth, Australia does not fit the world hydrological picture, and the models for stream hydrology successfully developed and tested overseas cannot simply be transferred to Australian streams. The hydrological uniqueness of Australian streams, manifested in such things as highly variable flows, is accentuated in north-east Queensland, where stream hydrology is influenced by monsoonal and cyclonic events. Here, even models developed for south-eastern Australia may not be appropriate.

The hydrological characteristics of north-east Queensland coastal streams are presented here in terms of the 16 river basins extending from the Daintree River to the Pioneer River (Figure 1.1 and Section 2.1) The basins' rainfall and runoff characteristics are summarised in Table 2.1, and the runoff volumes and depths are shown in Figure 2.4. The range of catchment size - from 490km^2 (Mossman River) to 129,000km^2 (Burdekin River) - coupled with the regional climatic variations across the three biogeographic zones (the wet tropics, the dry tropics, and the moist central coast) generate considerable diversity in catchment hydrology.

Interannual, Seasonal and Spatial Variations

Stream hydrology is primarily determined by catchment physiography and climate and is therefore directly related to the area and biogeographic conditions of the river basin. The interannual, seasonal and spatial variations in hydrology within the region closely follow the rainfall patterns described in Section 2.2, and are particularly influenced by monsoonal and cyclonic events. The marked variation in annual runoff volumes between river basins reflects the variation in both river basin areas and the annual rainfall within the three biogeographic zones. The basin runoff/rainfall figures (the percentage of rainfall converted to runoff) are least for the dry tropics (eg. 12% for the Burdekin River) and greatest for the wet tropics (eg. 74% for the Tully River), where the seasonal rainfall distribution is more even and evaporation conditions are less severe (Table 2.1 and Figure 2.4).

Figure 2.5 compares annual flow volumes and peak instantaneous flood discharges for north-east Queensland streams with national and global values and demonstrates the notable differences which occur. North-east Queensland streamflow data are based on the gauging stations and periods of record listed in Table 2.2.

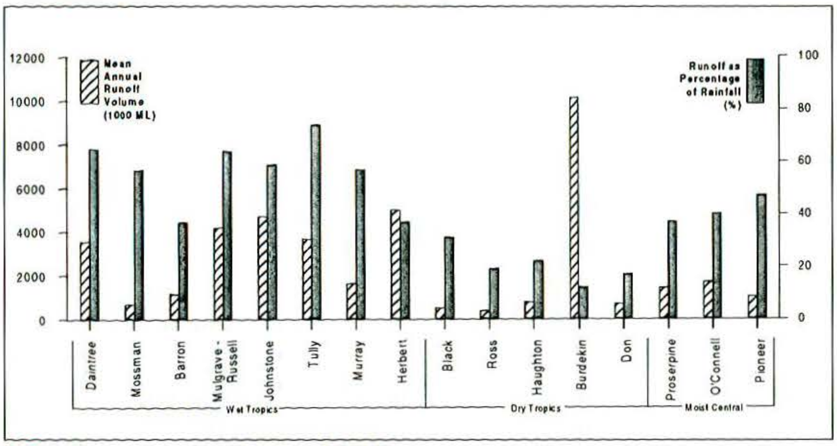


Figure 2.4 North-east Queensland coastal river basin runoff volumes and depths (as a percentage of rainfall)

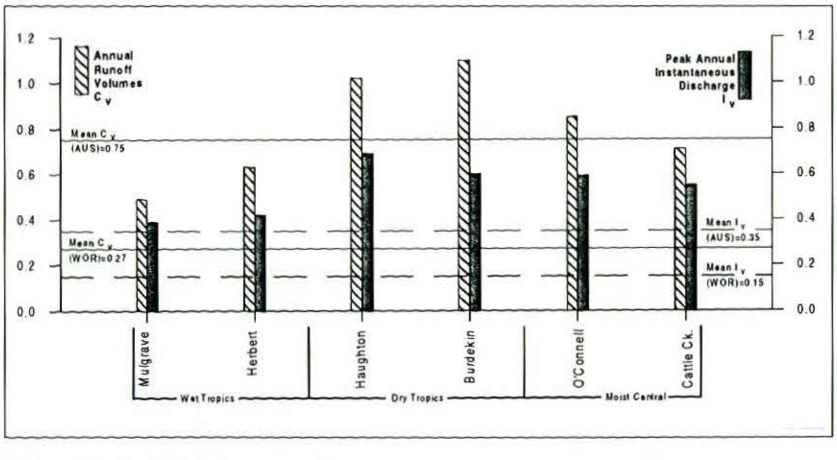


Figure 2.5 Variations in streamflow volumes and instantaneous discharge

C_v = Coefficient of variation of annual streamflow (runoff) volumes (standard deviation divided by the mean); I_v = Index of variability of peak annual instantaneous discharge (standard deviation of logarithm of flows). (Australian and world figures after McMahon 1982)

Table 2.2 Gauging station and streamflow data for selected streams

River Basin	Stream and Gauging Station Name	Distance from Stream Mouth (km)	Catchment Area at Gauging Station (km^2)	Gauged Area/ Basin Area (%)	Period of Record	Max Annual Flow Volume (1000 ML) (year)	Min Annual Flow Volume (1000 ML) (year)	Max Instant Discharge (m^3s^{-1}) (month year)	Max Period of No Flow (month) (year)
Wet Tropics									
Mulgrave - Russell	Mulgrave River Peets Bridge	38	545	27	1972 - 1997	1576 (1977)	206 (1992)	3354 (Feb 1977)	0
Herbert	Herbert River Ingham	30	8805	87	1915 - 1997	10 419 (1974)	371 (1992)	11 919 (Mar 1967)	0
Dry Tropics									
Haughton	Haughton River Powerline	33	1735	48	1969 - 1997	1635 (1991)	11 (1982)	3964 (Jan 1972)	11 (1986 /87)
Burdekin (Dam comp'd1987)	Burdekin River Clare	40	129 660	100	1950 - 1997	50 927 (1974)	540 (1992)	35 999 (Apr 1958)	3 (1966)
Moist Central Coast									
O'Connell	O'Connell River Caping Siding	17	375	15	1969 - 1997	567 (1979)	5 (1987)	3265 (Jan 1970)	6 (1994)
Pioneer (Cattle Creek)	Cattle Creek Gargett	11	340	23	1967 - 1997	937 (1979)	10 (1992)	2495 (Apr 1989)	2 (1992)

The ***interannual flow variability*** for the region is illustrated in Figure 2.6. The variability in annual flow volumes is more pronounced for dry tropics streams than for streams in the wet tropics or moist central coast. The ratio of maximum to minimum annual flow volumes is 148 for the Haughton River compared with 7.6 for the Mulgrave River. The coefficient of variation of the annual flow volumes (C_v) varies from 0.48 (Mulgrave River) to 0.65 (Haughton River).

Seasonal variability in streamflow, while typical of many Australian streams, is pronounced in north-east Queensland coastal streams, which have a distinct summer maximum flow and minimal flow during the dry winter months. Streams north of the Herbert River are mostly perennial, whereas south of this the flows are typically intermittent. Seasonal flow distributions (Figure 2.7) demonstrate that variability in mean monthly flow volumes is, once again, most pronounced for dry tropics streams such as the Haughton and Burdekin Rivers. For example, approximately 90% of the annual flow in the Haughton River occurs within the December to March period, whereas only about 55% of the annual flow in the Mulgrave River occurs in the same period.

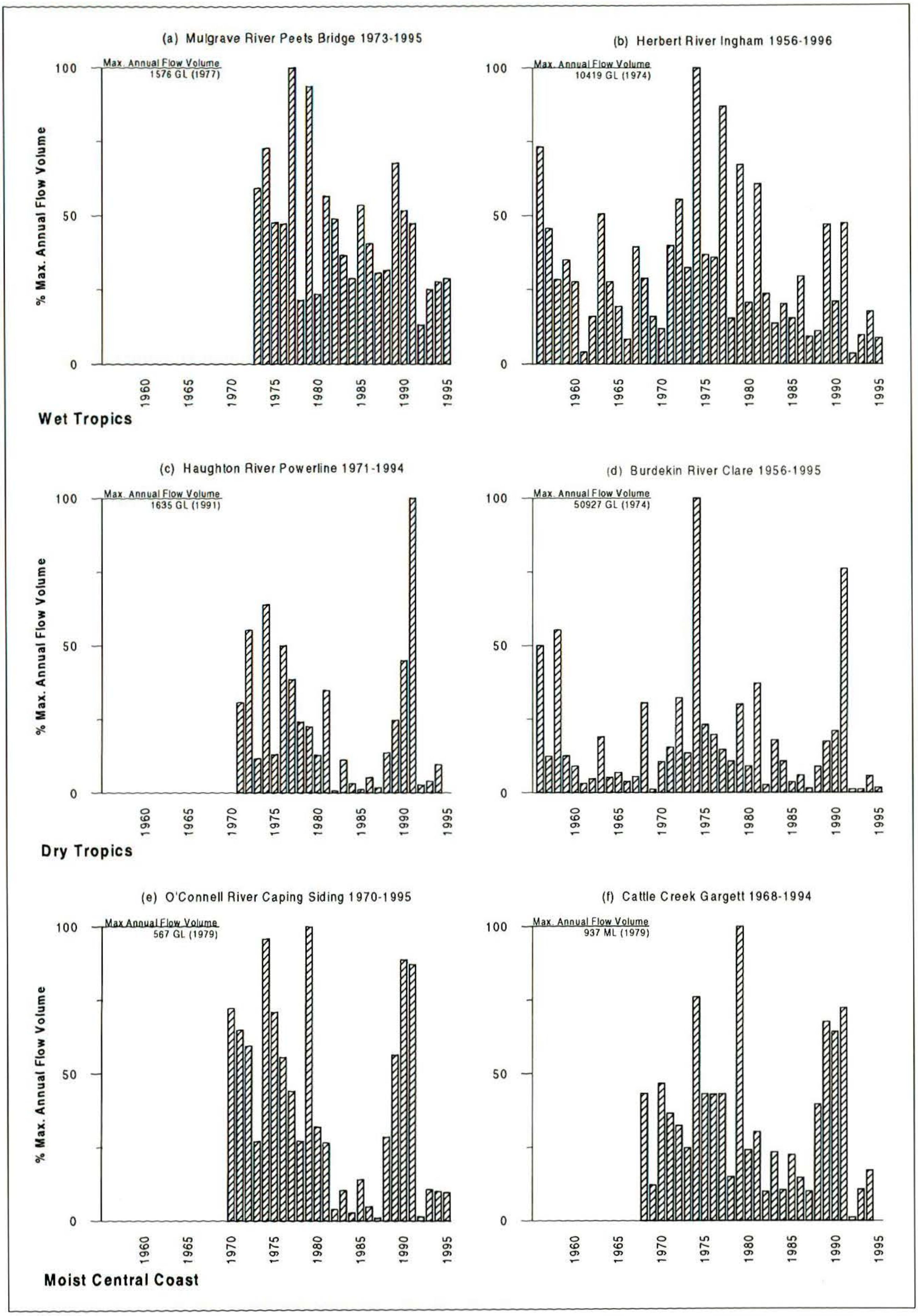


Figure 2.6 Interannual flow distribution

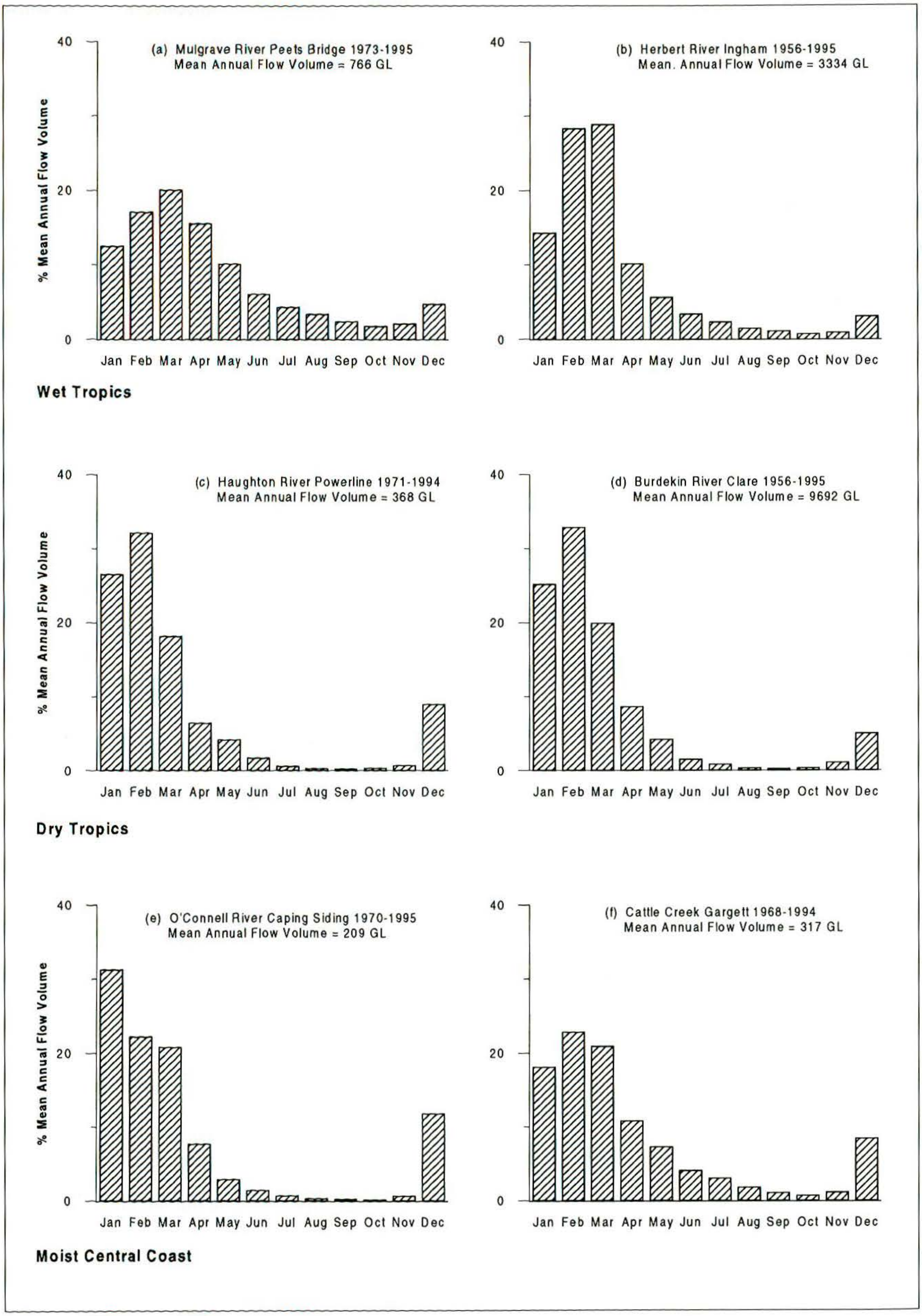


Figure 2.7 Seasonal flow distribution

Flood Magnitude and Frequency

The magnitude and frequency of major flood events significantly influence the formation and stability of stream channels and the lifecycles of instream and riparian flora and fauna. Regular streamflows and annual flood events in north-east Queensland streams have limited impact on stream morphology, and minimum structural and sorting influence on stream habitat. However, the less frequent, severe flood events associated with monsoons and cyclones may cause geomorphological changes to the stream, damage to adjacent land, infrastructure etc, and severe habitat disturbance when a discharge threshold is exceeded. The timing of floods also affects their geomorphological impact. Several floods in close succession can have a greater impact on channel stability than the same events at longer intervals, because streambanks which are wetted and stripped of vegetation are vulnerable to erosion.

The annual series of peak instantaneous flood discharges (the maximum flood discharge each year) for Australian streams are among the most variable for any streams in the world, demonstrating a similar pattern of variability to that for annual flow volumes. Whilst the mean annual peak discharges (the average of maximum values over a period of years) per unit catchment area are lower for Australian streams than for streams elsewhere in the world, the magnitudes of extreme floods are proportionately higher. Overall, Australian streams demonstrate a wide variation in the ratio of largest recorded flood to mean annual peak discharge. These variations are most pronounced in the streams within the study area.

The interannual and seasonal distributions of flood flows for selected streams within the region are illustrated in Figure 2.8. The wet tropics and moist central coast streams show a more regular pattern than do those of the dry tropics. Interannual and seasonal distributions of flood flows are also influenced by catchment area. Smaller catchment streams (eg. Cattle Creek and O'Connell River) are less variable than larger catchment streams. Although it does happen, it is uncommon for more than one major flood to occur in the same year in any of the river basins.

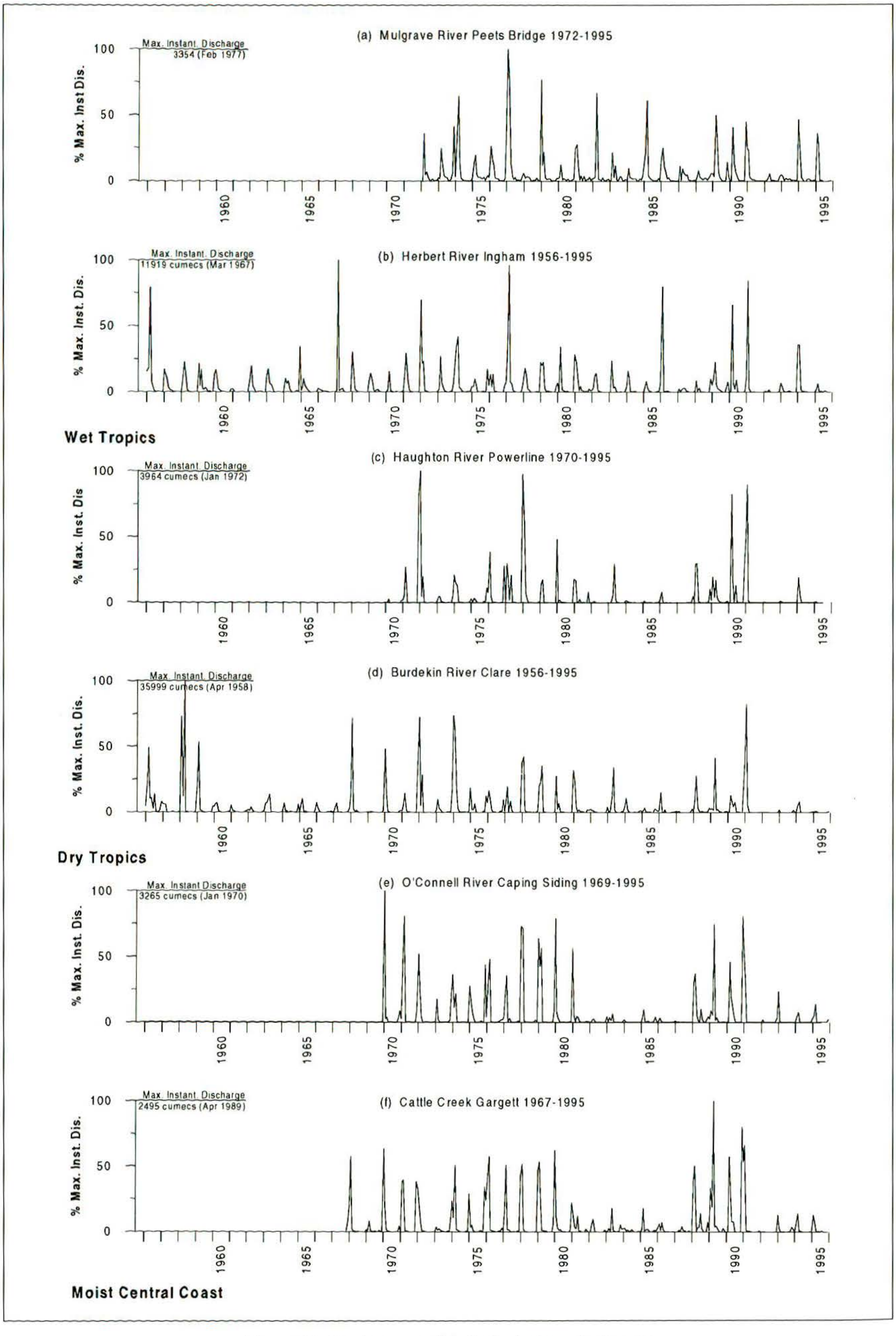


Figure 2.8 Maximum monthly instantaneous discharges

Flood Hydrographs, Flood Rise, Duration and Recession

Rates at which floods rise and recede and the duration of the flooding are major factors affecting streambank stability and stream ecological processes. Fluctuations within the stream channel (defined by the flood hydrograph) control streambank mass failure processes through build-up of subsurface water pressures during flood rise, and subsequent drawdown on flood recession (Section 2.5). Fluvial erosion, in which streambank or streambed material is removed in the flowing water, is directly affected by the duration of the flood.

Flood rise and recession rates are a function of rainfall intensity and duration and of the hydrological response of the catchment. This latter depends on area, steepness, and vegetation, and on human modifications (such as concrete-lined channels which reduce infiltration and increase flow velocity). Flooding in north-east Queensland resulting from monsoons and cyclones typically demonstrates sharply rising hydrographs. It is quite common for streams to reach flood peaks from a condition of virtually no flow in less than 24 hours. Rates of rise range from 200 mm/hr (sometimes experienced in the larger rivers such as the Burdekin and Herbert) to values in excess of 1,000 mm/hr (common in smaller and steeper streams such as the O'Connell River and Cattle Creek). Flood recession rates typically range from 100-500 mm/hr in the larger and medium-sized streams such as the Burdekin, Herbert, Haughton and Mulgrave Rivers, and may exceed 1,000 mm/hr in the smaller and steeper streams. Samples of flood hydrographs for the selected streams are shown in Figure 2.9.

Flood durations also depend on rainfall and catchment characteristics, and are described here in terms of the time of inundation above the lower third bank height. Flood durations may be less than one day for small floods in the small and medium-sized streams (eg. O'Connell River, Cattle Creek, Haughton and Mulgrave Rivers), and may exceed 2 to 4 days, particularly in the wet tropics. Large floods in bigger rivers such as the Burdekin may last for more than 10 days.

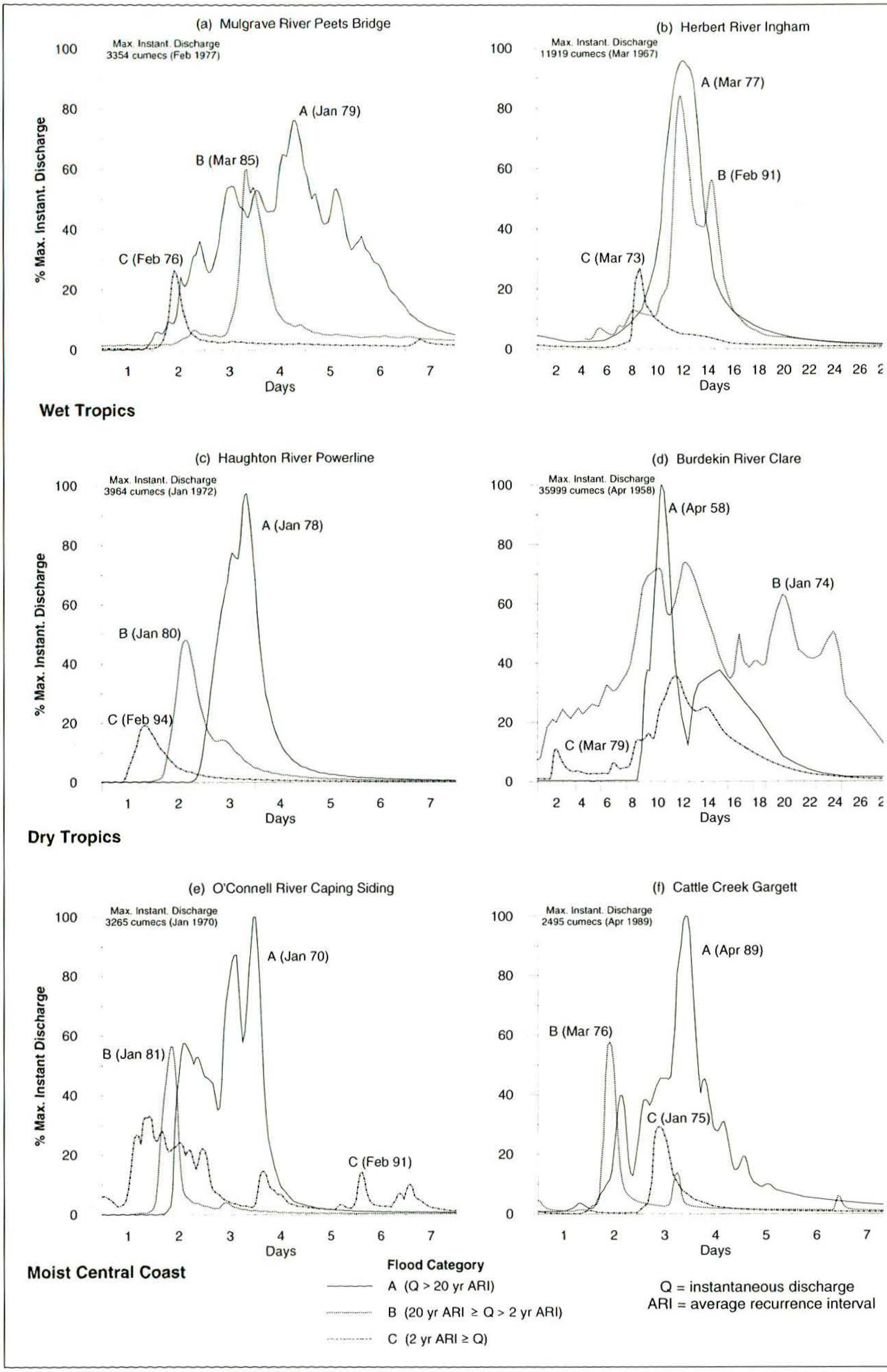


Figure 2.9 Flood hydrographs

Distributary Flood Flows and Downstream-decreasing Channel Capacity

Stream floodplains in the area are characterised by overbank and distributary flood flows, and by downstream-decreasing channel capacities which progressively reduce the channels' abilities to convey flow.

Natural levees typically border the main stream channels. These levees are sometimes elevated several metres above the floodplain, slope steeply away from the stream, and are commonly overtopped. Other flow channels, sometimes corresponding to old stream courses, are connected to the main channel in the lower reaches and may act as distributary (outflow) channels during higher flows.

The variation in main channel discharge affects stream channel velocities and therefore fluvial erosion and stream habitat characteristics. Overbank erosion is common at the flood outflow locations; flood inundation along these flood paths influences floodplain and wetland ecology, and commonly affects infrastructure and other human utilities.

Downstream-decreasing channel capacity and flood distributary characteristics are described below and are summarised for several streams in Table 2.3.

- The Mulgrave River and the Russell River experience major overbank flows on the floodplain.
- The flood capacity of the Tully River decreases downstream, and the average bankfull capacity of the Tully River channel on the floodplain is approximately 900 m^3s^{-1} compared with overbank flood flows of 3000 m^3s^{-1} for the 10 year ARI event.
- The Herbert River channel capacity decreases dramatically in the lower reaches, with over 90 % of total flood flow leaving the river through distributary channels and bank overflow in the 45km section between Long Pocket and Halifax Bridge.
- Similarly, the main channel capacity in the lower reaches of the Haughton River decreases by over 90% in the 20km from the Powerline gauging station to the tidal zone downstream of Giru.
- The Burdekin River channel has progressively diminishing thresholds for distributary channel outflows in the reach from Clare to downstream of the Ananbranch junction.
- The majority of flood flow in the Don River channel overflows from the river over an 8km reach on the floodplain.
- The flood capacity of the Proserpine River decreases by more than 90% from below Proserpine Gorge to the Breakaway channel, downstream of Proserpine.

The channel geometries of 30km sections of the lower reaches of the Herbert River and the Haughton River are shown in Figures 2.10 and 2.11. In the lower reaches of both, the streambank and streambed gradients converge, the channel cross-sections become shallower and narrower, and bankfull channel capacity decreases in the downstream direction. Peak flood profiles approximate the top of the streambank in both streams. As flood flow increases in the Haughton River, flood levels and the extent of overbank flooding at the downstream end of the stream increase slightly, and the extent of overflow moves progressively upstream.

Table 2.3 Downstream-decreasing channel capacities and flood distributary characteristics of selected streams

	Upper Floodplain		Lower Floodplain		Flood Outflow on Floodplain		
River	**Location (Distance upstream of mouth)**	**Bankfull Capacity (m^3s^{-1})**	**Location (Distance upstream of mouth)**	**Bankfull Capacity (m^3s^{-1})**	**Channel Length (km)**	**Outflow Discharge (m^3s^{-1})**	**Outflow (% of bankfull capacity on upper floodplain)**
Herbert	Long Pocket (55km)	11,000	Halifax Bridge (10km)	1000	45	10,000	> 90%
Haughton	Powerline GS (33km)	4000	Downstream Giru (13km)	< 400	20	> 3600	> 90%
Proserpine	Downstream Proserpine Gorge (45km)	1900	Breakaway (30km)	< 150	15	> 1750	> 90%

Flood Inundation, Flood Levels and Velocities

Physical processes such as streambank erosion and sedimentation, as well as ecological processes, are governed by flood inundation, flood levels and flow velocities in the stream and on the floodplain. Many of the streams in north-east Queensland do not form deeply-incised channels in their lowland reaches. Consequently, much of the streamflow occurs out of the channel across expansive and flat floodplains, forming, in their natural state, a variety of wetlands. Overbank flooding and extensive inundation of the floodplain is a common feature for all streams from the Daintree River to the Pioneer River. This affects agricultural development, coastal townships and rail and road infrastructure, causing economic damage and even loss of life.

Overbank flooding in the lower reaches of the Mulgrave and Russell Rivers occurs on average about every three years, inundating adjacent low-lying areas, and spilling into the neighbouring Babinda Swamp and Eubenangee Swamp (from the Russell River). Floods on the coastal plain are commonly 3 to 4km wide and more than 2m deep adjacent to the main river channels. The lower river terraces in the Johnstone River system are inundated by the five-year ARI flood, and widespread overtopping of the natural river levees occurs in the ten-year ARI flood. The Tully and Murray River floodplains are notable for the flood inundation that occurs virtually every year through flood breakouts and extensive transfer of flood waters from the Tully to the Murray River system. The bankfull capacity of the Herbert River on the floodplain corresponds to less than the five-year ARI flood, threatening severe damage from river breakouts across the neck of narrow bends, such as that at Long Pocket. The downstream-decreasing channel capacity of the lower reaches of the Haughton River causes extensive floodplain inundation for floods of less than five-year ARI. Outflows on to the floodplain of the Don River occur for floods greater than eight-year ARI. The natural flood overflow pattern prevails on the agricultural land adjoining the Proserpine River, and the urban area of Mackay, situated on the banks of the Pioneer River.

Whilst average channel velocities in excess of 3 ms^{-1} have been reported in the Don River (Plate 2.1), velocities in the lower reaches of most of the streams are expected to be less than 3 ms^{-1}. The average velocity during medium-size floods in the Haughton River channel reduces from about 2.0 ms^{-1} at the gauging station to 0.8 ms^{-1} downstream of Giru. Velocities in steeper streams, such as Cattle Creek and St Helens Creek, near Mackay, commonly exceed 5 ms^{-1}.

Plate 2.1 Don River flooding

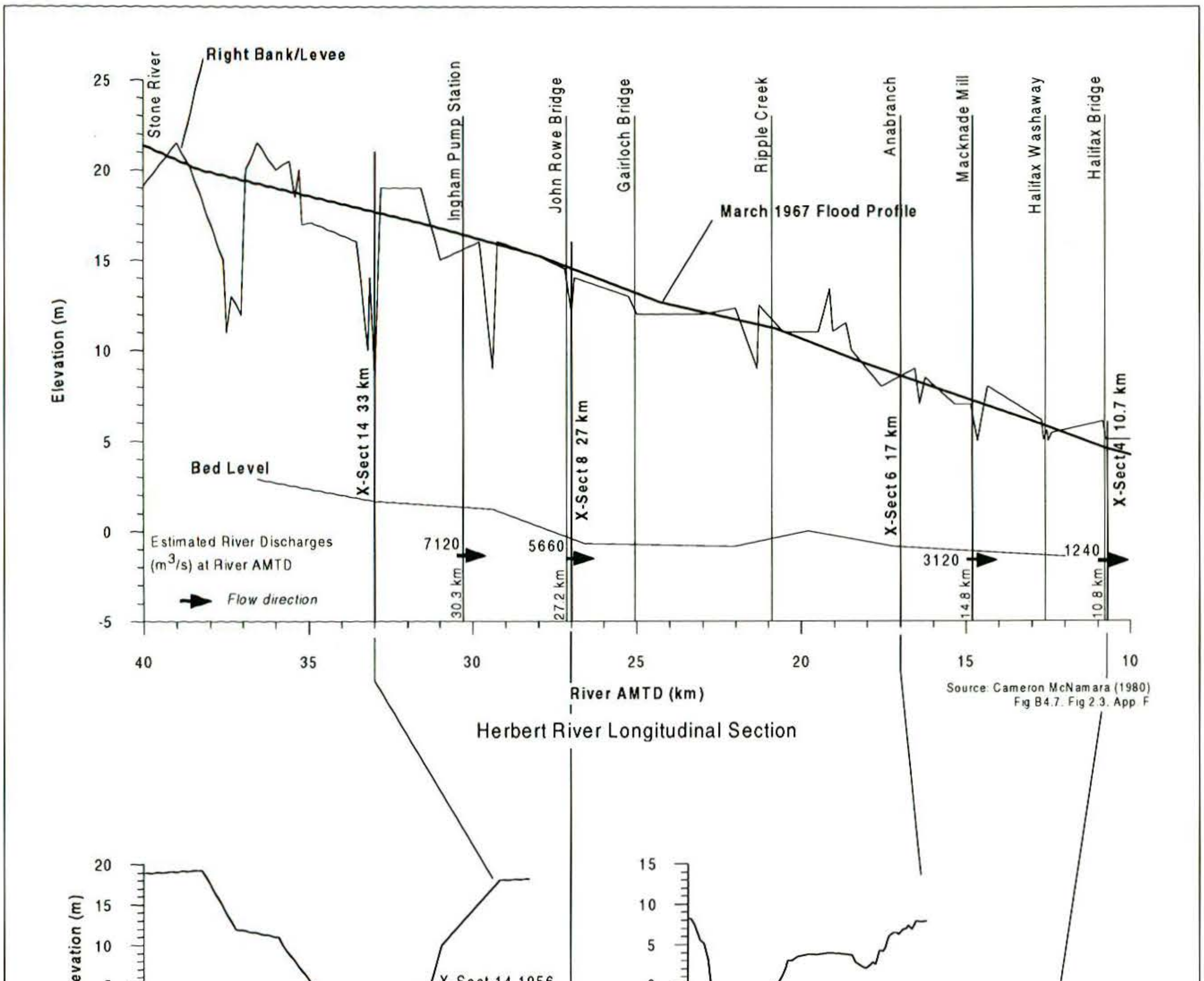


Figure 2.10 Herbert River longitudinal section and cross-sections

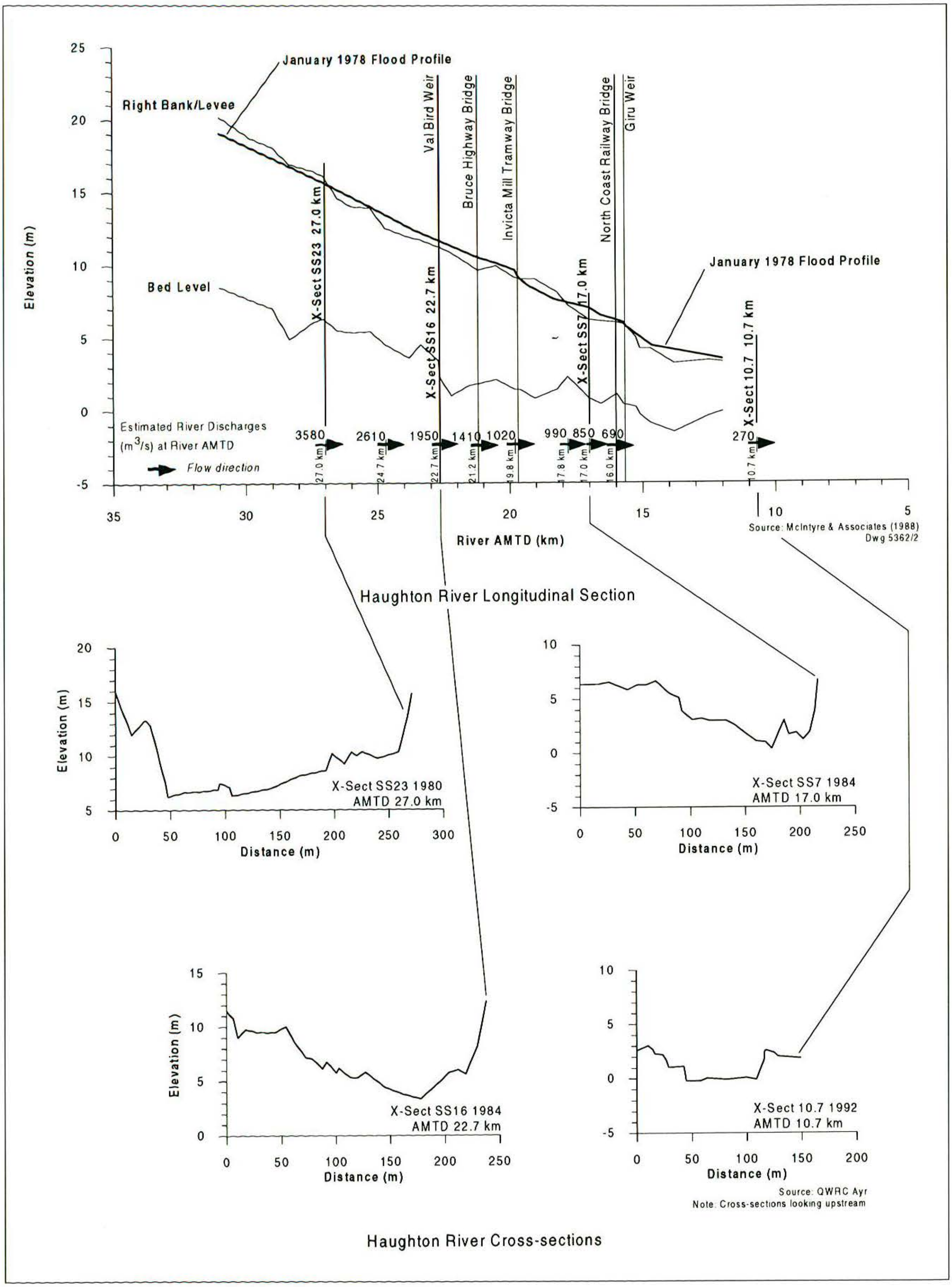


Figure 2.11 Haughton River longitudinal section and cross-sections

2.4 Geomorphology

Streams are dynamic entities which naturally change their form in response to changes in a range of variables, including discharge, sediment load and channel boundary conditions. In managing streams it is important to be aware of what is likely to initiate stream changes in particular areas, how much change can be expected, and where and when it is likely to occur. An understanding of the geomorphology of streams in the area provides such insights.

Geology and Landforms

The geology of north-east Queensland is complex, but may be broadly described as a coastal floodplain of Quaternary (the geological period covering the last two million years) alluvium up to 50km wide, bounded to the west by a regional escarpment and bedrock hills. Residual bedrock hills (usually granitic) rise from the coastal plain throughout the region (eg. Mount Elliot, Mount Inkerman). In some areas they form more continuous coastal ranges (eg. The Malbon Thompson, Bellenden Ker, Seaview and Clarke Ranges). Colluvial aprons and broad alluvial fans have formed at the base of these elevated features, and extend out over the coastal plain. A plateau of broad rolling tablelands, punctuated by remnant hills of resistant granitic bedrock, lies to the west of the escarpment. Basaltic deposits associated with relatively recent volcanic activity occur throughout the region, and are particularly extensive around the Atherton Tablelands. Extensive areas of deep basalt deposits are found on the Tablelands, and extend towards the coast where the basalt flowed down stream valleys (eg. North and South Johnstone Rivers).

The major landforms of the region largely reflect the differential resistance of the underlying geology to erosion. It is generally agreed that the Tablelands formed as a result of the uplift and warping of a previously flat area which followed the fracturing of the eastern edge of the Australian continent around 100 million years ago, and created a relatively steep eastern face. Erosion by high energy streams flowing over the steep surface rapidly transformed this feature into a steep escarpment, and has persisted to cause the escarpment's westward retreat to its present position. The continental shelf, coastal plains and alluvial corridors between the remnant hills and ranges have remained in the wake of the escarpment as it has gradually migrated west. Many of the alluvial corridors linking the uplands to the coastal plain follow courses that reflect the alignment of resistant geological formations, so that streams generally flow parallel to the direction of the more resilient geologies. This pattern is exemplified by the Mulgrave River, which runs NNW-SSE in its upper reaches, where it is confined between the Bellenden Ker and Malbon Thompson Ranges (Figure 2.12).

Alluvial fans composed of gravelly material have accumulated where the streams flow out on to the coastal plain. These fans may be composite features formed over a long period or during several episodes, with older, pre-Holocene (>10,000 years old) units recognisable by their cementation and ferruginised appearance. Fan sediments usually grade gradually from coarse to fine toward the fan toe. Many of the alluvial corridors and parts of the coastal plain were choked with sediment prior to the last ice age (around 18,000 years ago). The lower sea levels associated with the last ice age subsequently initiated a phase of channel downcutting through this alluvial material, and rejuvenated many coastal stream systems (Willmott and Stephenson, 1989).

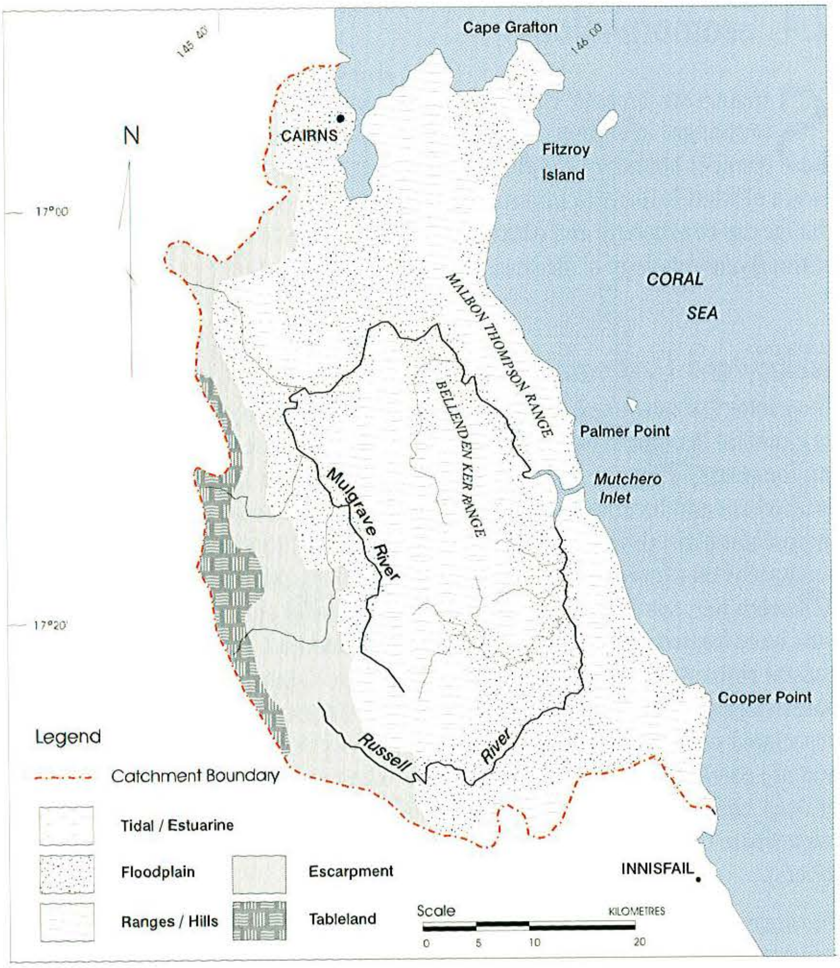


Figure 2.12 **Russell-Mulgrave River basin: major physiographic units and stream path**

The landforms of the coastal plain are mostly depositional and include well developed river meanders and levees, river terraces, and backswamps. The coastal plain over most of the region has rapidly prograded (grown) seaward since the mid-Holocene period, when sea-levels rose to near their present level. Progradation was especially rapid near the mouths of major rivers, with rates estimated to exceed more than one kilometre per thousand years. It is not yet known if late-Holocene progradation was continuous or episodic. At the coastal fringe, complex estuarine systems occur in the tidal reaches, and are often occupied by varied and extensive mangrove communities backed by saline flats.

Channel Forms

Channel form is conveniently examined using the graded stream concept. This concept suggests that streams adjust their longitudinal profile (grade), planform and cross-sectional shape to maintain a balance or equilibrium between the energy supplied by stream flow (discharge) and the energy dissipated in overcoming resistance to flow and in transporting sediment. To achieve this balance, natural streams tend to move in a course that equalises and minimises the rate at which energy is expended along their length.

Each of the dominant variables influencing channel form (stream discharge, sediment load, boundary resistance) can vary spatially (both along and between streams) and with time, and all can be influenced by human activities within the catchment (Figure 2.13). Nevertheless, the downstream increases in discharge, and reductions in mean sediment size and gradient that characterise most streams produce a predictable series of downstream changes in channel form (Figure 2.1).

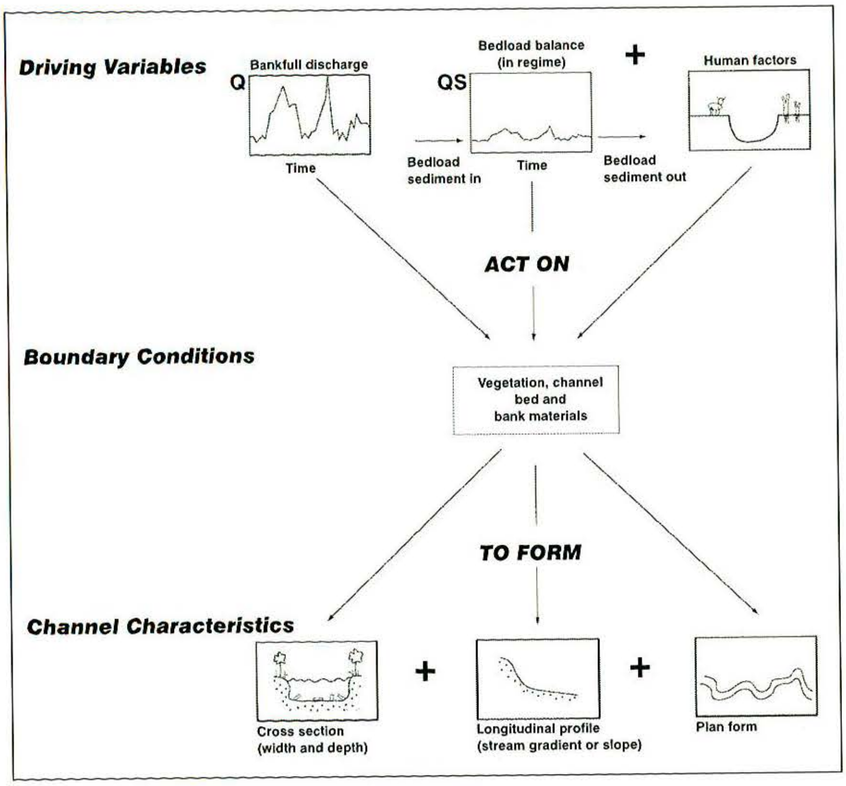


Figure 2.13 Schematic representation of variables influencing channel form (after Brookes, 1992)

Two major types of channel can be identified according to the nature of the material through which they flow. Bedrock channels are cut into rock and are relatively stable, with modifications to channel form occurring gradually over long periods of time. Bedrock channels are usually restricted to the source zone of the stream system (Figure 2.1) where there is sufficient stream energy to abrade large sediments, export finer sediments, and incise into more resistant boundary materials. In north-east Queensland, bedrock channels are generally restricted to stream headwaters near the top of the escarpment or over steep escarpment slopes. The gorges of the Barron and Herbert Rivers provide good examples of bedrock channels. These gorges formed over millions of years as the streams incised down and cut back into the escarpment rocks through the process of knickpoint retreat (Plate 2.2).

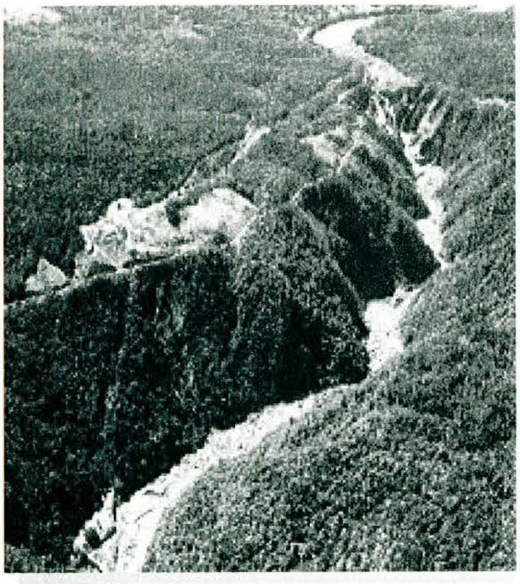


Plate 2.2 The Barron River Falls and Gorge: A bedrock stream channel

The bed and banks of alluvial channels are composed of sediment deposited by the stream or its ancestors. Typically, these channels occur in the sediment transport (transition) and deposition (lowlands) zones (Figure 2.1), although in north-east Queensland the transition zone occupies a narrow belt at the foot of the escarpment and the majority of alluvial channels are situated in the lowland areas of the coastal plain.

Channel boundaries composed of alluvium are relatively erodible. Alluvial channels can undergo rapid and marked changes in form as a result of changes in discharge and sediment load in the stream catchment, and/or as a result of direct human impacts on the stream (such as channelisation and clearing of riparian vegetation). The dynamic adjustment of alluvial channels to altered sediment and/or discharge regimes, combined with the extensive human use of alluvial floodplains is the root of many stream management problems, both in the region and globally. The following discussion focuses on the planforms and cross-sectional profiles adopted by alluvial channels, because the majority of streams in the study area are, over most of their length, alluvial channels (Plate 2.3) flowing across the alluvial deposits of the coastal plain and piedmont fans that foot the surrounding hills and ranges.

Plate 2.3 The Tully River: An alluvial stream channel meandering over the coastal plain

Alluvial channels develop a great variety of forms but are often classified as meandering, braided or straight. Each of these channel patterns develops in response to variations in sediment load and stream energy, and each has a relative stability (Figure 2.14) ***Straight channels*** are rare, although several rivers in north-east Queensland (eg. the Burdekin, Haughton, Herbert, and Don Rivers) have sections of relatively straight, high-flow channel that are active only during the large floods that may occur several times a decade. The low-flow channels nested within the main banks are active most of the time, and, depending on local sediment transport competency, typically exhibit meandering or braided characteristics at various locations (Plates 2.4 and 2.5). They may switch from a predominantly meandering to a braided character (or *vice versa*) if sediment or hydrologic regimes change. Changes in sediment regime may happen quickly in response to catastrophic events such as landslides or avulsions, or gradually as the river migrates through floodplain units composed of sediments of different character. Similarly, hydrologic regimes may change rapidly, in response to factors such as catchment clearing, channelisation, or the installation of flow-regulating infrastructure (such as dams), or they may change slowly, in response to gradual changes in runoff, infiltration or even microclimate.

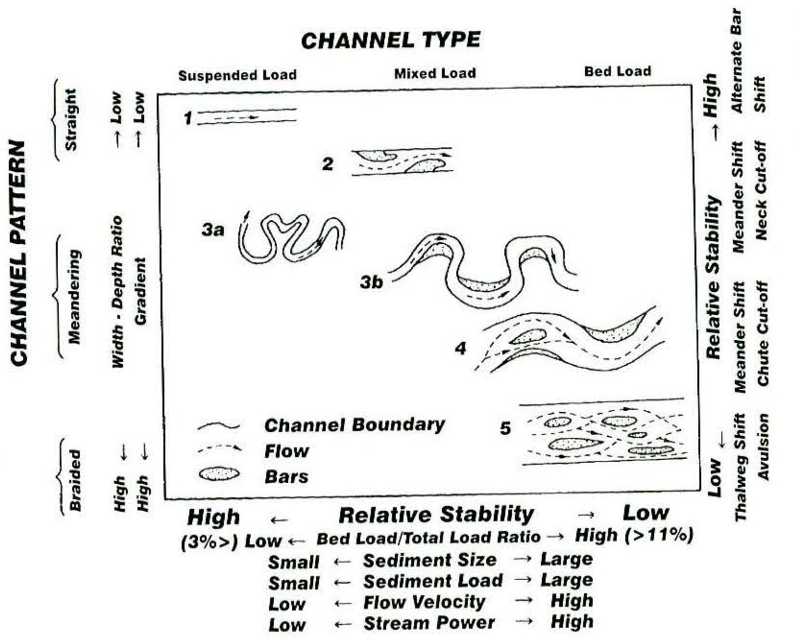


Figure 2.14 Classification of channel form based on pattern and sediment load (after Schumm, 1981)

Plate 2.4 The Burdekin River below the Gorge, showing low flow channel nested within high flow banks

Plate 2.5 The Burdekin River near Home Hill
Source: Sunmap aerial photo, Ayr 1971, Run 6, No. 83

Meandering alluvial channels are the most common stream type in the study region. Meandering channels have a sinuosity (a ratio of channel to valley length) in excess of 1.5, and are best-developed in low gradient streams carrying predominantly fine (suspended and mixed) sediment. These streams transport less than 11% of their total sediment load as bed load, and typically have width to depth ratios of less than 40:1.

Although natural meanders are seldom perfectly symmetrical, meandering streams usually exhibit several common morphological characteristics. For example, meander wavelength is typically around ten times the channel width and about five times the mean radius of curvature (Plate 2.6). The regularity with which these patterns occur indicates that meanders are not the result of purely random processes such as local differences in bed and bank cohesion, but rather a function of an internal property of the stream, such as excess free energy. Most streams have more energy and less work to do as discharge increases and sediments become finer in their lower reaches. By developing meanders a stream is able to increase its length and reduce its gradient to minimise and uniformly spread energy expenditure along its course. Shear and turbulence in the water flow, induced by friction with the bed and banks, promotes the formation of alternate bars along the channel, and thereby initiates meander development. A helical current flow pattern is established by the alternate bars, with higher velocity flows occurring on the outer bank of each curve and returning deep in the water toward the downstream point bar deposits, where currents slow. Higher velocity currents erode the outer bank, with eroded material being deposited on the next point bar downstream (Figure 2.15).

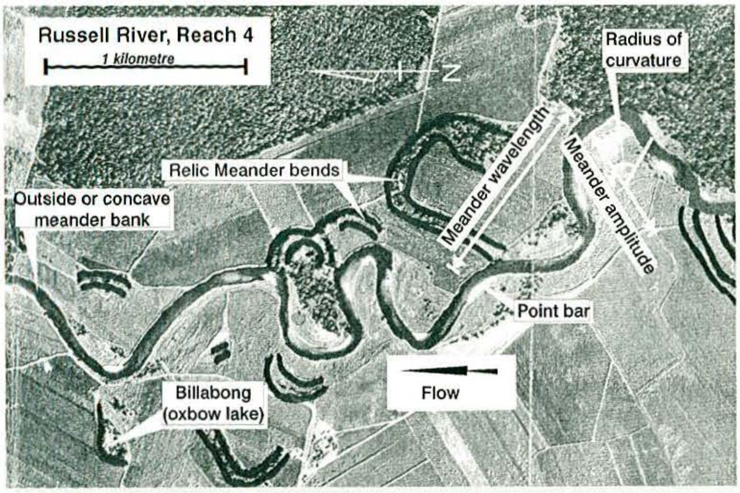


Plate 2.6 Meanders on the Russell River, annotated to show the principal components of meander geometry (after ID&A, 1994)

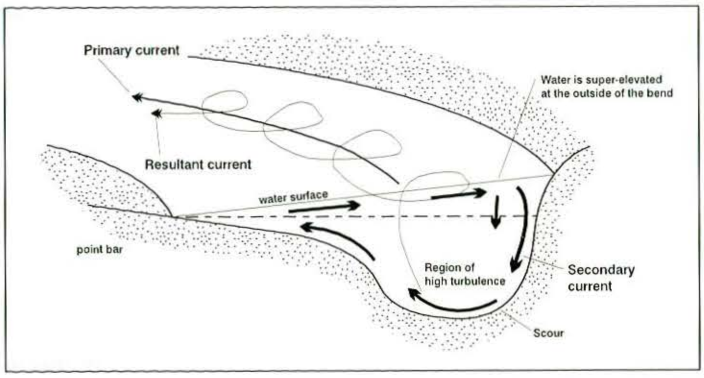


Figure 2.15 Schematic representation of helical flow currents acting on the outside of a meander bend (Raine and Gardiner, 1995).

Braided alluvial channels are less sinuous than meandering streams and are divided by islands or bars. Despite the diversion of streamflow around these features, braided channels are single channel forms. Streams usually develop braided channels when sediment load is high and coarse, banks are erodible, and discharge is high relative to slope (Figure 2.14). Many braided streams also experience highly variable discharge. Cattle Creek, a relatively steep, coarse load channel in the upper reaches of the Pioneer River catchment, provides an excellent example of this. Generally, braided streams are relatively straight, broad and shallow, allowing a relatively high energy per unit of stream length and bed area to be devoted to the transport of coarse bedload material. Stream bedloads may be increased where:

- coarse material is introduced to the channel by landslides or by tributaries;
- the stream flows through coarse alluvium deposited under higher discharge regimes;
- the channel widens or midstream bars form due to bank destabilisation and channel blockages; and
- human activities such as alluvial mining initiate massive increases in sediment load.

An increase in stream gradient, discharge or sediment load may also cause a channel to change from a meandering to a braided pattern. By developing straighter, higher-gradient channels, braided streams are able to maintain the balance between sediment transport and available energy. Meander development is inhibited in braided streams because, in steep gradient, high velocity flow settings, the downstream flow momentum prevents the formation of alternate bars. The combination of erodible banks and high gradients, high flow velocities and high stream powers means that braided streams are prone to channel shifts and are often considered unstable.

Anastomosing alluvial channels, with their branching and reconnecting pattern, superficially resemble braided streams. However, whereas braid bars and islands are rarely stable in the long-term, the material separating anastomosing channels is usually comparatively resistant bedrock or stable alluvium that assists in retaining the channel patterns.

The location of different channel types within the river basins of north-east Queensland suggests that the planform and cross-sectional profiles of the alluvial stream channels are principally a function of the quantity and size of the sediment load and the landscape gradient.

In the dry tropics, streams may adopt a braided low-flow channel pattern within the high-flow banks as dry season discharge falls below that needed to transport the sediments deposited during wet season flows. An example of this can be seen in the lower reaches of the Don River. Alternatively, this pattern may develop in steeper areas at the foot of the escarpment, over colluvial and alluvial fans composed of coarser sediment, or where sediment loads become excessively high for the prevailing discharge (eg. due to landslides or inappropriate landuse). By comparison, meandering streams predominate over the more gently-sloping floodplains, where they often drain old alluvial and colluvial deposits that are heavily weathered and highly cohesive. Streambanks composed of such material are normally quite resistant to erosion, and meandering streams flowing through these deposits are typically deep and carry a mostly suspended sediment load.

Although channel pattern and shape reflect the influence of many inter-related factors, channel dimensions are largely a function of stream discharge (ie. stream discharge and cross-sectional area are positively correlated). A cornerstone of the dynamic equilibrium theory of fluvial geomorphology developed for temperate perennial streams is that channel form reflects flow magnitude and frequency, usually measured as the bankfull discharge. This theory assumes that bankfull flows are large enough in magnitude and high enough in frequency to exert the greatest cumulative influence on stream morphology. The theory may be less applicable to the seasonal tropics, particularly the intermittent streams south of Townsville. These streams typically experience prolonged periods of little or no flow punctuated by episodic high volume flows that can vary considerably in volume and intensity from year to year. Recent work suggests that streams of this type develop nested channel-in-channel morphologies, with a set of high banks associated with high magnitude floods and a set of lower banks in balance with regular seasonal flows (Gupta 1995). It appears that the channel planform and cross-sectional profile of streams in the study region are more likely to be influenced by an equilibrium change (occurring when the critical streamflow (or stability) threshold (dynamic metastable equilibrium) is exceeded) than by the conventional model. It is quite likely that stream behaviour in large catchments with high discharge, such as the Burdekin, may diverge significantly from standard stream models.

Many streams in the region, and indeed in coastal eastern Australia, do not increase their channel size in the lower reaches to accommodate higher cumulative discharge volumes as predicted by fluvial theory. Instead, they shed much of their discharge over the floodplain as overbank flow. As described in Section 2.3, the channel capacity of the Herbert and Haughton Rivers reduces by over 90% on the coastal plain (Figures 2.10 and 2.11). The corresponding downstream increase in bankfull flood frequency means that standard procedures, such as conventional hydraulic geometry relationships to establish 'suitable' streamflow-channel configuration, may not be appropriate.

Channel Processes

Channel changes are a natural and often predictable phenomenon for most alluvial streams, although they may be initiated and/or accelerated by human activities. Earlier notions of complete lateral stability in natural alluvial streams are now considered unrealistic; even 'stable' alluvial channels will undergo some changes in position, size and/or shape under natural conditions. Recognition of some 'natural' channel change is particularly relevant to coastal north-east Queensland streams, which are especially prone to channel changes as a result of climatic, hydrologic and physiographic factors (eg. cyclonic rains and flooding, high inter-annual stream flow variability, areas of high and steep relief vulnerable to mass movements, and episodic massive sediment influx). Identifiable channel changes through the region include:

- shifts in channel position associated with meander migration (eg. Stewart Road, Mulgrave River; Airport Bend, Barron River);
- meander cutoffs (eg. Russell River, east of Babinda Swamp);
- avulsions (eg. Le Feuvre, Haughton River; Foulden, Pioneer River); and
- changes in channel form associated with changes over time in sediment load and discharge.

Extended periods of above- and below-average streamflow can be identified for many streams in the region, and have been linked with changes in streambank morphology. For example, periods of channel expansion and contraction of the Pioneer and Burdekin Rivers can be associated with such streamflows. A number of common processes associated with channel movement are outlined below. It is not unusual for more than one of these processes to be occurring at a site. Consequently, effective management requires recognition of the predictability of relationships between stream process and form, and of their interplay and influence through the entire stream system.

Bank erosion is a natural or human-induced process which contributes to the movement of streams and to floodplain formation. It occurs as either scouring, which is the direct removal of material by flowing water, or slumping, a type of mass movement that occurs when bank material slips or falls into the stream channel. Scour is caused by the tractive force of water flowing over bank material. Slumping is often triggered by bank undercutting, channel deepening, or drawdown of the floodplain water table through the bank as flood levels recede rapidly (Section 2.5). In meandering streams, scour-induced bank erosion is usually concentrated on the outside banks of meander bends, where current velocities are greatest. Natural processes of meander migration and deformation sustain a natural amount of bank erosion, and destabilised outer banks (often with reduced or damaged vegetative cover) are vulnerable to continued scour. Scour is often followed by slumping, as undercut bank material collapses into the channel. The highly erodible banks typical of braided channels are susceptible to bank erosion along their length, but most erosion occurs where flows are diverted toward the bank by instream braid bars and islands. Scour may also occur in both meandering and braided channels, where changes in hydrologic and/or sediment regimes produce changes in channel shape and dimensions.

Although slumping can be initiated when scouring undercuts and/or oversteepens stream banks, slumping can also develop independently where saturated stream banks are destabilised by their increased weight and high pore water pressures associated with rapid drawdown. Slumping is particularly a problem for higher banks composed of fine, poorly drained material (refer to Section 2.5). Factors that may contribute to or accelerate bank erosion include the removal of protective vegetation, altered catchment sediment and/or hydrologic regimes, bank saturation, accelerated flow around stream blockages, streambed instability, and the construction of infrastructure that upsets the natural equilibrium between stream energy and channel form.

Channel incision or deepening is another process common in streams of the region. It is most pronounced where streams flow through alluvial fan deposits at the base of the escarpment and bedrock hills; where, in many catchments, stream terraces are preserved (eg. the Stone River, Upper Herbert Catchment). Stream terraces can develop in response to natural changes in channel gradient, discharge or sediment loads. The conspicuous stream terraces preserved at the back of the coastal plain in many of the catchments of the region can generally be attributed to lowered base levels associated with lowered sea levels during the last Ice Age.

Stream incision can cause large increases in channel grade, in stream power, and in channel dimensions. Severe bank erosion usually follows channel incision, with the increased channel capacity further promoting bank instability. The focus of channel incision typically moves upstream, either as an advance of a reach of high gradient or as a major erosion head, transferring its effect throughout the system. Material removed by channel incision is deposited downstream, often causing channel aggradation. Aggraded channels choked with sediment in the downstream reaches experience higher flood frequencies, and are inherently unstable. Areas of stream aggradation are particularly prone to channel avulsions and anabranch development. Several workers have described changes in the courses of coastal streams in the region and speculate that they are associated with incision and aggradation due, at least in part, to lowered sea levels. For example, Wilmott and Stephenson (1989) note that the Mulgrave River has switched from a course flowing north toward Trinity Inlet to its present southerly course toward Mutchero Inlet.

Human activities that may trigger stream incision include channel straightening; flow regulation, diversion, and concentration; modified sediment loads; and destabilisation of the stream bed by excessive sand and gravel extraction and/or overzealous channel clearance. These activities may also reduce channel roughness and further accelerate incision by increasing the tractive stress on the channel bed.

Channel avulsion is the development of a new or additional stream course on the floodplain. Avulsions are most likely to occur where there is a sudden drop in transport capacity (for example, following a sudden change in channel gradient, an increase in sediment load or a decrease in the capacity of the stream to transport sediment). This causes the existing channel to infill, possibly broaden, and subsequently break out of the existing channel. These conditions are most likely to occur in depositional settings, such as on alluvial fans at the foot of the coastal ranges or in deltas closer to the coast. Avulsions may be preceded by crevasse splays, in which the channel breaks through the levee bank during high flows and deposits lobes of sediment on the floodplain (eg. Le Feuvre, Haughton River). Avulsions are a natural process in streams of the region, but human activities may increase a stream's susceptibility to this process. Changes in land use that increase sediment load or decrease sediment transport capacity may be influential, as may the clearing of riparian vegetation.

Geomorphic Thresholds

Stream behaviour can be analysed in terms of exceeding thresholds (a switch from gradual to abrupt changes) within and outside the stream system. Progressive in-channel sedimentation that continues until the gradient at the downstream end of the deposit exceeds a critical limit and initiates incision, is an example in which a threshold is crossed as a result of internal stream processes. Another example is where meanders develop and sinuosity increases until meander bends overlap and meander cutoff occurs. External factors that can induce a threshold response include tectonic or climate change, and human activities such as landuse changes and disturbance of the streambank. Geomorphic thresholds are important to stream managers for two reasons.

First, unexpected dramatic changes in stream form and/or integrity have tended to be attributed to external factors when no direct causative factor is readily apparent. However, these changes may stem from the intrinsic properties of the stream itself if thresholds have been surpassed.

Second, stream channel adjustment to new equilibrium conditions need not be immediate or steady; different components of the stream system may respond at different rates to threshold changes, that is they may exhibit a 'complex response'.

Rates of Channel Change

The time since the last Ice Age is most important in considering the geomorphic development of the lowland streams in the region. Streams have adjusted over this period to a change in base level and to changes in climate, discharge and sediment load, and have deposited much of the landscape in which today's channel changes occur. While there is relatively little detailed information on the recent evolution of the lowland floodplains and deltas throughout the region, several rivers (eg. the Burdekin and Mulgrave Rivers) are known to have shifted channel position since the last Ice Age.

Rates of channel change in the region since European settlement have varied considerably between channel reaches and catchments, reflecting factors such as channel size, hydrologic regime, bank materials and human disturbance. Some reaches of some streams have been remarkably stable for the period for which records are available, while others have moved considerably over the same period (eg. Russell River, near Babinda swamp, Plate 2.6). Whilst it is possible to establish a rate of change by simply dividing the spatial movement of the stream bank by the time between data collection (usually in the form of cadastral maps or aerial photographs), a rate so established is, at best, a crude approximation of stream behaviour. It is impossible to infer whether the change occurred gradually or episodically, or even whether all the change has been in one direction. For example, early cadastral maps indicate that the Lower Russell and Mulgrave Rivers have shifted considerably (in places by hundreds of metres) over their floodplains since European settlement. However, aerial photographic coverage since 1952 suggests that they have remained relatively stable over the last few decades.

It is also important to consider the implications of spatial scale. For example, a 40m lateral migration of the Burdekin River in its lower reaches, where it is approximately 750m wide, may be less significant than a 10 metre displacement of the Mulgrave River channel near Stewart Road, where it is less than 50m wide.

2.5 Geotechnical Aspects of Streambed and Streambank Instabilities

Streambed and streambank instabilities (bed and bank erosion) which affect adjoining land and infrastructure are among the most prominent and spectacular problems experienced in streams. Utilities such as buildings, bridge foundations and agricultural land threatened by bank erosion or undermined by bed erosion have traditionally been high priorities for remedial action, and will continue to be the focus for streambank stabilisation activities. To develop appropriate remediation programs for these bed and bank instabilities, the manager must understand the geotechnical aspects of the site within the context of the stream's physical and biological environment, identify the type of instability and failure, and understand the factors that contribute to the instability.

Instabilities can be broadly classified as either fluvial erosion (scouring) or mass movement (slumping). Fluvial erosion is the direct removal of material by water (rainfall or streamflow) and is closely linked to the processes of sediment transport and deposition (Plate 2.7). Mass movement is the bulk movement of material, generally as a result of decreased material strength, or, in some cases, increased loading on the streambank (Plate 2.8). Fluvial erosion may occur in either of the three zones of the stream cross-section (bed, bank and overbank), whereas mass movement is restricted to the streambank. Mass movement and fluvial erosion in the bank zone are commonly interrelated (Figure 2.16). The slumped material that is deposited at the toe of the bank following mass failure may be removed by scour, potentially leading to further slumping failure. Similarly, fluvial erosion of material from the toe of the bank undermines the upper bank material, which may then fail by slumping, and be removed by further fluvial erosion.

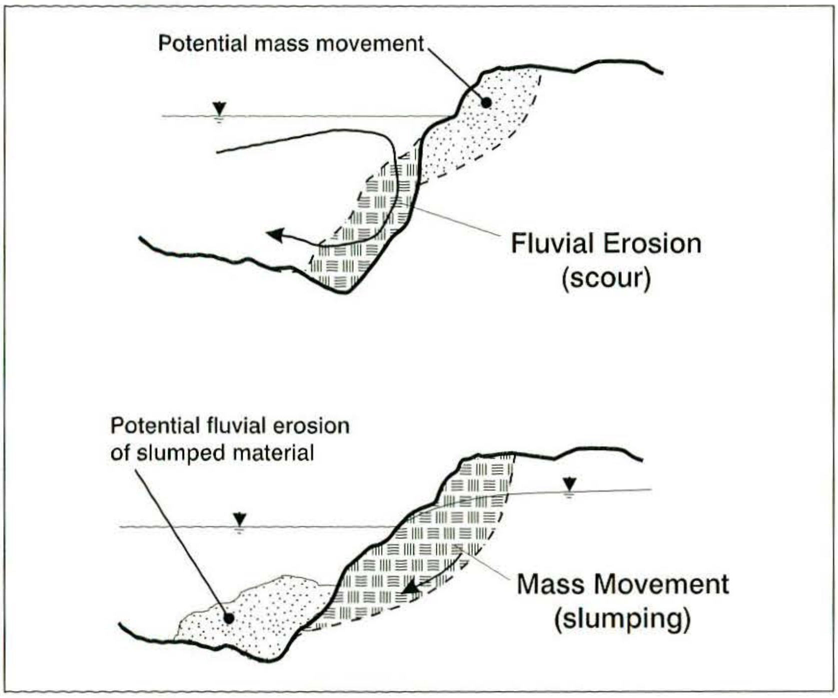


Figure 2.16 Interrelation of fluvial bank erosion and mass movement

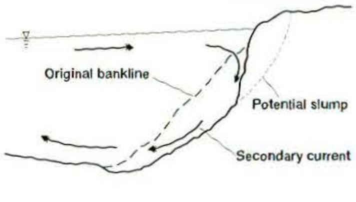
Plate 2.7 Fluvial bank erosion

Plate 2.8 Mass Movement

Modes of Fluvial Erosion (Scour)

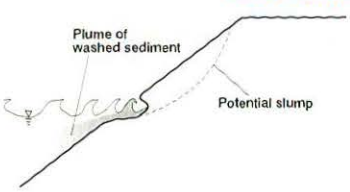
Fluvial erosion occurs when particles are dislodged from the streambed or bank by the impact of raindrops, wind or vessel-induced waves, or by erosion from stream flow or propeller wash. If the impact or erosive forces exceed the resistive forces provided by cohesion and binding agents within the soil, particles are dislodged. The principal modes of scour erosion relevant to streams in north-east Queensland are direct bank scour and wave erosion (bank erosion), overbank erosion, and headcut (bed erosion). These modes are represented below and are described and illustrated in Appendix B.

Direct Bank Scour



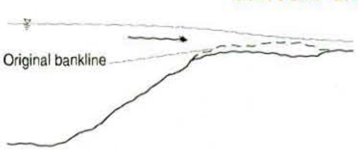
Direct scouring of bank materials occurs when water flowing in the stream entrains surface materials from the bank. Entrainment may occur as a result of primary streamflow, turbulence or secondary currents in bends (Figure 2.15). In each case, the net movement of material is a function of the sediment load and the sediment's resistance to entrainment. Erosion of the toe of the bank causes undercutting, which can lead to slumping of upper bank materials. Likely causes of direct bank scour are changes in the sediment and flooding regimes and disturbance to banks.

Wave Erosion



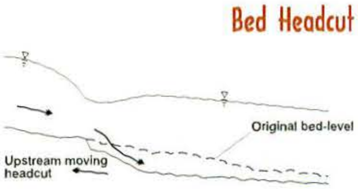
Waves generated by boats or wind can cause erosion in bank materials near the water surface. Fine soil particles are washed from the surface by the wave, leaving behind coarser particles such as sands that eventually fall into the stream. This process causes the retreat of the bank in the wash zone to form a characteristic 'S'-shaped beach, and can lead to slumping of the upper bank materials. Likely causes of wave erosion are boating, wind action and disturbance of the bank.

Overbank Erosion



Overbank erosion can occur when runoff flows into the stream or when flood water flows out of the stream and onto the surrounding floodplain. Erosion from outflow can entrain natural levee material and so lower the bank, further increasing the outflow problem and possibly leading to a major change in the course of a stream or to a meander bend cutoff. Erosion that occurs during inflow commonly causes localised bank incisions (gullies). Clearing of the bank and the surrounding floodplain influences both outflow and inflow overbank erosion because flow velocities are increased when the retarding influence of the vegetation is removed, and the surface soils are disturbed and exposed to eroding forces.

Bed Headcut

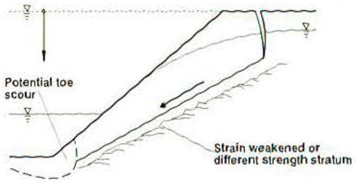


Bed headcuts lower bed surface levels in the stream. Usually initiated as a scour hole in the stream bed, the head cut moves upstream as the localised acceleration of flow over the cut causes high velocities that entrain bed materials from the upstream face of the cut. Upstream movement of the scour continues until equilibrium of the sediment and hydraulic regimes is achieved or until a scour-resistant section of bed is encountered. This lowering of the bed level oversteepens and so destabilises the banks. Headcuts are typically caused by channel straightening, dredging of materials, flow concentration or restriction, and by sediment deficiencies caused by instream structures.

Modes of Mass Movement (Slumping)

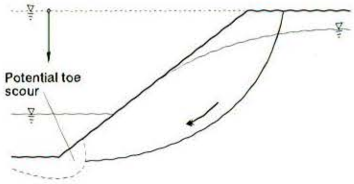
The four principal modes of mass movement failure in alluvial streambank deposits are translational, rotational, retrogressive and tunnelling erosion. Each of these may occur in north-east Queensland, usually during or immediately after flood recession. The particular mode of movement depends on the bank stratigraphy, soil properties and the presence of any existing failure surfaces. The basic mechanisms of the four modes of mass movement are described below.

Translational



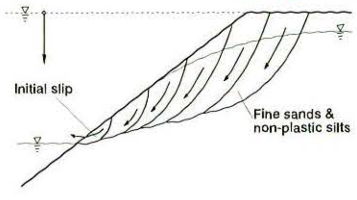
Translational movements occur where the failure surface is influenced by an adjacent stratum of significantly different strength, or where a weakened surface has developed as a result of some initial movement. These types of failures usually occur along a failure surface that is planar, roughly parallel to the slope, and at a relatively shallow depth. Movement occurs soon after a flood has receded, sometimes leaving the distinctive failure surface intact. Compound failures are similar. Here, the failure surface is defined by curved and planar sections of significantly different strength materials.

Rotational (shallow & deep seated)



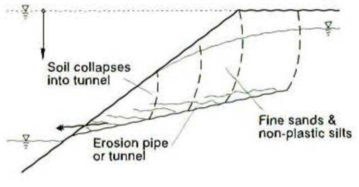
Rotational bank movements characteristically occur in homogeneous cohesive soils. The failure surface follows a near-circular arc that typically passes through a region near the toe of the bank. In deep-seated failures, which commonly occur in highly-cohesive materials, the volume of material involved is relatively large. In less cohesive soils, movements are shallower and involve less material. The failed material rotates, causing subsidence near the top of the bank, and bulging up near the toe. Non-homogeneous soil conditions, having variable strength properties, often display non-circular failure surfaces. As with translational slides, this failure mode often occurs immediately after or during flood recession.

Retrogressive



Retrogressive bank movement is a variation of shallow rotational failure that occurs in fine sands and low cohesion silts, often in conjunction with seepage from the bank. The retrogressive failure starts with a small rotational failure in the region of the seepage face. This oversteepens the adjacent bank, initiating another rotational failure, and progresses until a lower, stable slope is achieved, or until the soil above the most recent slip has sufficient strength/cohesion to inhibit further failure. This explains how some apparently deep-seated failures have developed in slopes that otherwise appear too flat to be unstable.

Tunnelling Erosion



Although tunnelling erosion (piping) is different from the typical mass movements, the processes are closely related and the prerequisite conditions are much the same as for retrogressive movements. Movement is initiated when seepage flows wash individual particles from the seepage face, which retreats into the bank, thus forming a tunnel into which the overlying material eventually collapses. Since the results are similar to retrogressive instabilities, it may be difficult to distinguish between the two types unless the process is actually observed, or unless the final condition of the slope preserves part of the earlier tunnel structure. Soils that are susceptible to this type of instability are fine sands, silty sands and non-plastic silts, which have saturated cohesion and permeabilities low enough to allow the development of significant rapid drawdown conditions.

Factors Influencing Streambed and Streambank Instabilities

The location, extent and frequency of streambed and streambank instabilities depends on intrinsic site characteristics such as bank configuration, soil properties and vegetation, and extrinsic factors such as streamflow, surface drainage and stream modifications. The attributes relevant to fluvial erosion and mass movement are summarised in Table 2.4 and the relevance of each of these factors is described in the subsequent sections. These factors are represented diagrammatically in Figures 2.17 and 2.18.

Table 2.4 Factors influencing fluvial erosion and mass movement

Factor	Major Attributes influencing Streambed or Streambank Instability	
	Fluvial Erosion	**Mass Movement**
Intrinsic Site Characteristics		
Channel planform location	meander bend, toe of bank, structure location	n.a.
Bank configuration	surface disturbance and irregularities	slope, height, tension cracks
Stratigraphy	homogeneity, layered	homogeneity, layered, weak zones
Recharge and subsurface drainage	n.a.	configuration, flow capacity
Soil properties	moisture content, cohesion, grain size	cohesion, internal friction, permeability
Vegetation	retardation, interception	restraint, interception, transpiration
Sediment load	transport capacity	n.a.
Extrinsic Site Characteristics		
Streamflow	duration, velocity, rate of rise	height, duration, rate of recession
Surface drainage	flood outflow, drainage inflow	ponded water
Surcharge	n.a.	infrastructure, machinery, vegetation, dredging spoil
Stream modifications	channelisation, dredging, constriction, flow deflection	revetment, subsurface drainage
Boating	waves, propeller wash	n.a.

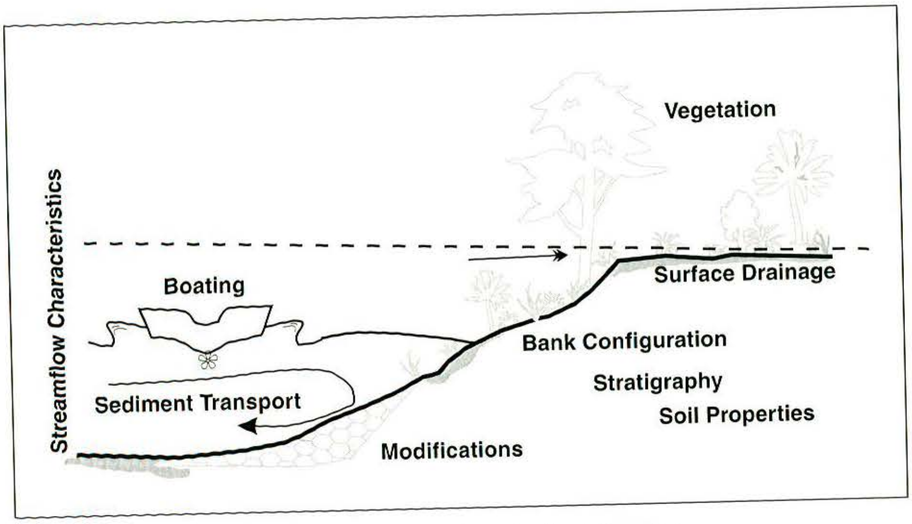


Figure 2.17 Factors influencing fluvial erosion

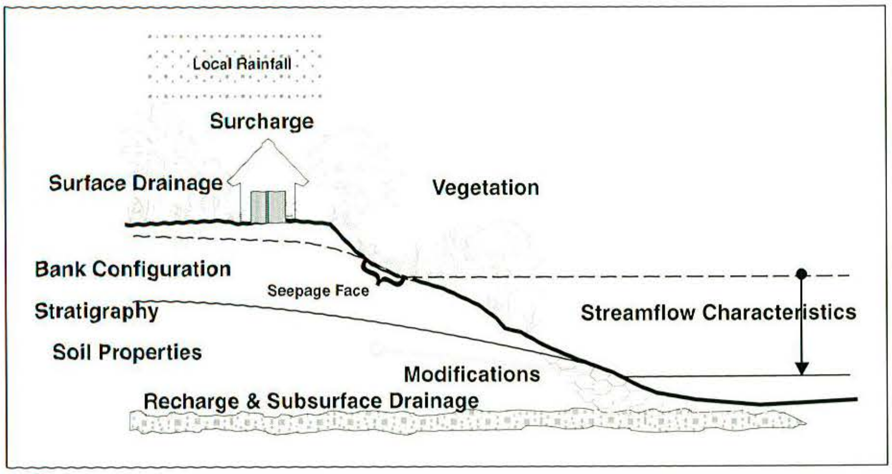


Figure 2.18 Factors influencing mass movement

Factors Influencing Fluvial Erosion

Fluvial erosion and deposition may occur at a local scale, even in streams that are considered to be in a state of equilibrium. In contrast, extensive erosion may occur in unstable streams that are undergoing large changes as they evolve to a more stable configuration. Fluvial erosion is influenced by a number of factors relating to the physical and biological condition of the stream and human impacts on the stream system.

Planform Location and Fluvial Erosion

Fluvial erosion can occur at any location on a stream, but some parts of a stream are more prone to erosion than others. High flow velocities and strong secondary currents make the outer bank of meander bends vulnerable to fluvial entrainment. Fluvial entrainment is accentuated in high velocity regions downstream of relatively straight channel reaches. Deposition of sediment typically occurs on the point bar of the meander bend.

Local features in the stream can initiate fluvial erosion of surface materials. Constrictions induced by a culvert, deflections caused by bridge piers, and hydraulic jumps induced by weirs or bed chutes can modify flow patterns, increase turbulence and increase erosion.

Bank Configuration and Fluvial Erosion

The attributes of bank configuration that affect fluvial erosion are predominantly related to the surface condition of a streambank, such as disturbance of surface soils and the presence or absence of surface irregularities.

Surface material can be disturbed by the removal of vegetation, grazing, human recreation and factors such as burrowing by animals. Disturbance generally loosens the surface material, making it vulnerable to surface abrasion or fluvial entrainment from rainfall, surface runoff or flooding.

Large surface irregularities, such as vegetation and large rocks, that are resistant enough to survive flood flows can reduce streamflow velocities adjacent to the surface and so reduce entrainment. Alignment training treatments such as groynes or retards (Appendix C) increase irregularity along the bank line and so reduce streamflow velocities against the bank and, thus, reduce fluvial bank erosion.

Stratigraphy and Fluvial Erosion

The configuration and material properties of the streambank soils affects their susceptibility to fluvial erosion. Soils are typically classified according to their cohesion as 'cohesive', 'non-cohesive' or 'layered'. Cohesive banks typically comprise clays that are *resistant* to erosion. Non-cohesive banks typically comprise silty sands and sands that are *vulnerable* to erosion. Layered banks combine cohesive and non-cohesive materials and can be vulnerable to both erosion and mass movement, depending on the position of materials.

The nature of alluvial bed and bank materials varies longitudinally on streams within the study region. Bed alluvium is generally finer towards the sea. Bank and overbank sediments tend to be finer than the adjoining bed sediments, but may vary substantially across the stream section. Floodplains typically have a coastal fringe of estuarine areas where bed and bank materials consist of saline to hypersaline, high plasticity marine clays. These clays are intermingled with varying amounts of silt and peat and are often interspersed with sand layers (such material is observed near the mouth of the Barron River). These estuarine areas are prone to scour and/or mass movements initiated by undercutting of the bank. Upstream of the coastal fringe, streambanks comprise mostly non-cohesive alluvial deposits within the upper section and erosion-resistant materials in the region of the toe. The lower extent of the non-cohesive deposits occasionally extends below the bed level but still overlies the more erosion-resistant materials. The non-cohesive deposits include fine sands and low plasticity sandy silts (sandy loam) that are susceptible to mass movements and fluvial erosion. The erosion-resistant materials include cohesive soils such as sandy clays, clays or even bed rock (such as in the Burdekin and Lower Pioneer Rivers and the Herbert River Anabranch).

Soil Properties and Fluvial Erosion

Soil properties that influence fluvial erosion are cohesion, moisture content and particle size. Cohesion is typically controlled by the finer fraction (fine silts and clays) of particles in the soil, and is reduced upon soil wetting. The high proportion of the very fine particles in clays produces a bonding chemistry and resultant cohesion at all moisture contents. Silts, with slightly larger particles than clays, exhibit capillary suction that causes an apparent cohesion. This effect is significantly reduced when the silt becomes saturated. Sands exhibit no cohesion. The highly cohesive nature of clays makes dislodgment of individual particles difficult, whereas silt and sand particles are easily dislodged, particularly when saturated.

The moisture content of a soil can affect its susceptibility to erosion. Because soil cohesion generally decreases as the moisture content increases, soils are more vulnerable to erosion as they become wetter. This effect is least in clays, which are very slow to wet and which retain most of their cohesion, and greatest in sands and silts, which convey water quickly and lose most of their cohesion when saturated.

High velocities are required to mobilise large particles, such as gravels, cobbles and boulders, whereas smaller particles, such as sands and silty sands, are mobilised at lower velocities and are more susceptible to fluvial erosion. Cohesive forces in saturated clays make clay particles difficult to entrain in spite of their small size.

Vegetation and Fluvial Erosion

Vegetation can reduce the entrainment effects on streambank materials by reducing stream velocities adjacent to the bank, by reducing particle dislodgment through lessening the impact of raindrops and waves, and by increasing the erosion resistance of the bank by binding the soil with the root systems. Vegetation that is flattened during flooding can form erosion-resistant mats that protect the surface of the bank. Removal of vegetation frequently leads to fluvial erosion.

Sediment Load and Fluvial Erosion

Net erosion is a function of the properties of the bed and bank material and the erosive power of the streamflow. Where sediment transported by the stream is less than the sediment transport capacity, net erosion will tend to occur. Sediment in streams can be affected by clearing of vegetation in the catchment (which often tends to increase sediment load), or water storage facilities (such as dams which reduce sediment loads immediately downstream).

Streamflow and Fluvial Erosion

Streamflow characteristics that influence fluvial erosion of bed and bank materials include flood duration, pre-flood water levels, and peak flood discharges. The most severe erosion is usually associated with long flood durations, and high flood slopes (water surface gradient). Long flood durations inundate bank materials and reduce soil cohesion, thus making bank materials more susceptible to erosion. High flood slopes produce high flow velocities which increase fluvial entrainment.

Surface Drainage and Fluvial Erosion

Clearing of vegetation and provision of surface drainage on the streambank and floodplain increases the likelihood of fluvial erosion from flood outflow or drainage inflow.

Stream Modifications and Fluvial Erosion

Stream modifications that influence fluvial erosion include structures that deflect or constrict streamflow (such as bridge piers, culverts and revetments) and activities that alter the stream morphology and stability (such as dredging and channel realignment). The consequences of stream modifications need to be assessed at, and remote from, the works site.

Boating and Fluvial Erosion

Boating can cause entrainment of bed materials by propeller wash, and dislodgment of bank material by bow waves. Entrainment from propeller wash typically occurs when craft are manoeuvring in shallow depths. The generation of bow waves depends on the hydrodynamics of the craft's hull and the speed at which it is travelling. Bow wave abrasion can occur extensively on a stream, commonly undercutting the bank and promoting mass movement of the upper bank.

Factors Influencing Streambank Mass Movements

Mass movement failures are common in the alluvial streambank deposits in north-east Queensland. Streambank mass movements are influenced principally by stratigraphy and soil properties, vegetation and stream modifications, streamflow and subsurface water conditions.

Bank Configuration and Mass Movement

The bank configuration features that influence mass movement are slope and height and the presence or absence of tension cracks.

Stable bank slopes depend on the strength properties of the bank materials and the presence of any binding agents, such as vegetation, that increase the bank strength. Steep slopes are more susceptible to mass movement than shallow slopes. Cohesive bank materials, such as clays, which exhibit measurable tensile strengths even when wet, are more likely to be stable at steeper angles. Slopes close to vertical are often maintained on cohesive, vegetated banks. Non-cohesive materials, such as sands, without any binding agents, can usually only stand as shallow slopes (commonly much less than 40°). Some non-cohesive materials, such as silty sands, exhibit a measurable cohesion when unsaturated. This cohesion can allow the materials to maintain stable angles of greater than 45° when the material is moist but, when the material becomes very wet, the apparent cohesion is lost and the bank reverts to a much flatter slope.

Tension cracks, sometimes present on the surface or tops of banks, tend to decrease bank strength. The cracks develop as a result of tension caused by soil drying (common in cohesive materials) and/or movement, and can extend for several metres below the surface. These cracks can shorten the failure surface, thereby decreasing the shear resistance, harbouring runoff water, imposing additional hydrostatic loads on the bank, and allowing more rapid ingress of water to the profile.

Stratigraphy and Mass Movement

Streambank stratigraphy can significantly influence the mode of mass movement. For example, streambanks without layering may be susceptible to large mass movements. Drainage layers can reduce the effects of overloading resulting from bank saturation. Layers of different strengths can provide conditions suitable for translational sliding. Underlying highly-cohesive layers can confine the propagation of failure surfaces to overlying less cohesive layers.

Recharge, Subsurface Drainage and Mass Movement

Streambank mass movements commonly occur when the subsurface water levels in the bank remain above the falling water levels in the stream. This condition, referred to as 'rapid drawdown', typically occurs when streambanks that have been saturated prior to or during the flood rise are subjected to a rapid recession of flood waters.

Streambanks may be saturated by the recharge of subsurface water, which results from irrigation on the streambank, direct rainfall, overbank flooding, and/or flood inundation from the stream. Recharge typically causes the watertable to rise, increasing the likelihood of rapid drawdown failure. The extent of the rise depends largely on the drainage characteristics of a site, which are governed by the material permeability and the connection with a drainage pathway. In general, where drainage layers are hydraulically connected with a shallow watertable, water drains from the bank during flood recession and for some time after the flood. These recharge and drainage characteristics are common in the Burdekin River and Herbert River (Box 2.1), where major flood events can wet bank materials and provide the conditions for rapid drawdown during a rapid flood recession.

Box 2.1 Subsurface Water Monitoring

Subsurface water movements have been observed at the Bube study site on the Herbert River Anabranch (Chapter 4, Case Study 2) where a longitudinal drainage pipe has been installed as a trial stabilisation treatment. A rising watertable prior to and during rising flood levels in the stream has been recorded (Figure 2.19). The rate at which the watertable rises and falls is typically slower than the rates of rise and fall of water levels in the stream, and so flooding in the stream reaches a peak height and starts to recede before the peak watertable height has been reached. The differences in subsurface and stream flood levels during flood recession are minimal near the face of the bank, but are significant beyond the top of the bank. These characteristics are attributed to the longitudinal drainage pipe, which effectively removes water from the toe of the bank. It appears that this type of treatment may be effective in reducing mass movements caused by elevated watertable levels.

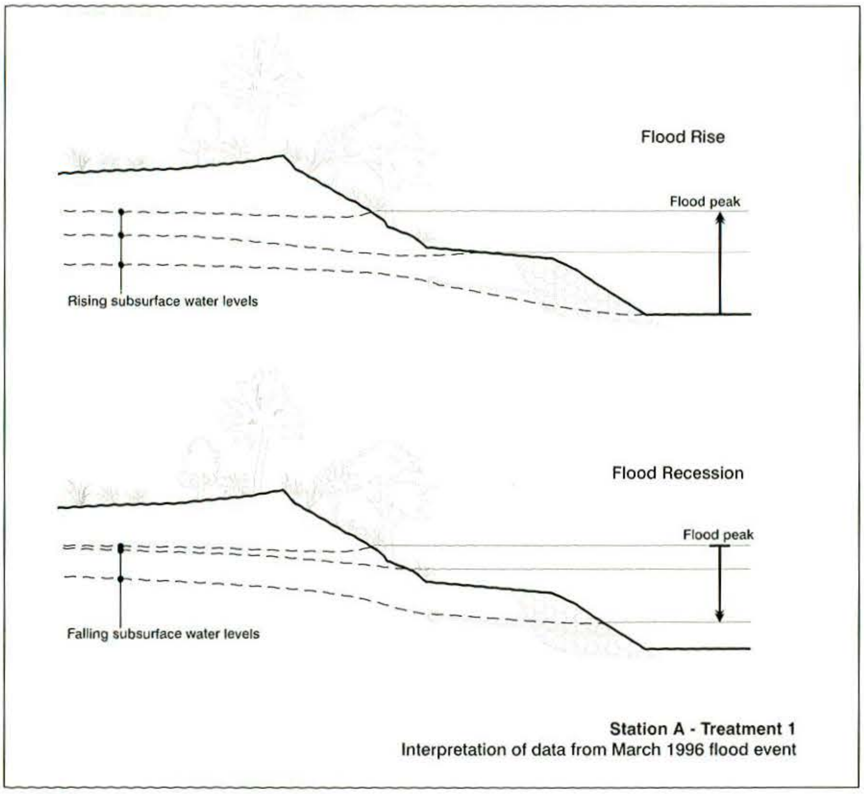


Figure 2.19 Subsurface water monitoring results, Herbert River Anabranch Bube (see Case Study 2)

Soil Properties and Mass Movement

Soil properties that influence mass movement are soil strength (cohesion and internal friction angle) and permeability. Sands typically have higher internal friction angles than clays, but have much lower cohesion. Coarse-grained materials (such as sands) are more permeable than fine-grained materials (such as clays). Table 2.5 lists typical values of cohesion, internal friction and permeability from streambank investigations.

The type of mass movement depends on the properties of the soil. For example, soft clays, because of their high cohesion, low permeability and low internal friction angles, are susceptible to deep rotational failures, whereas saturated silty sands, which exhibit moderate permeability, moderate internal friction and low cohesion, are prone to fail at shallow depths. However, when dry, the same silty sand materials display an apparent cohesion due to negative pore pressures and they can then form near-vertical slopes. This has been observed at the Burdekin River Swindley and Herbert River Anabranch Bube sites.

Table 2.5 Typical values of cohesion, permeability and internal friction angle

Soil type	Cohesion[a] *c, (kPa)*	Internal friction angle ϕ, *(deg)*	Permeability k, (cm/hr)
Clay	60-100[b]	15-25	$\leq 10^{-4}$
Silty sand	0[c]-15[d]	30-40[d]	0.36-7.2
Sand	0	35-45[e,f]	18-36[g]

Notes: a) decreases with wetting; b) overconsolidated values; c) saturated; d) dry; e) increases with increasing dry density; f) changes with grain size; g) increases with increasing grain size (adapted from Eckersley 1993 & 1995)

Vegetation and Mass Movement

Riparian vegetation increases resistance to bank instability by mechanically increasing the strength or apparent cohesion of the soil. Vegetation may also contribute to stability by intercepting rain and runoff and by transpiration, keeping soils drier and delaying the onset of soil saturation. This effect is not likely to be significant in north-east Queensland due to the magnitude of the rainfall.

The influence of root systems on stability varies between species of vegetation. Root systems range from very fine fibrous systems to systems dominated by a vertical taproot. Soil type and the groundwater regime also strongly influence root development. Roots in well-drained soils extend deeper and exploit a much larger volume of soil than those in wet soils. Areas that have a high groundwater table or a layer of densely-compacted soil will force roots to spread laterally.

Much of the riparian vegetation in north-east Queensland has been cleared or otherwise degraded by agricultural and urban development. Intact vegetation that remains on the slopes of the banks is often substantially degraded by infestation with exotic grasses which are typically shallow-rooted, and which contribute less to bank stability than the deep-rooted native riverine trees and shrubs.

Streamflow and Mass Movement

The streamflow characteristics that can affect mass movement of streambanks include the overall height of flooding, flood duration, and the rate of flood recession (Box 2.2). Rapid drawdown conditions may initiate streambank failure when flood levels reach the upper portions of the bank and when the flood has a long duration and a relatively fast recession. These flood conditions may lead to mass movements in silty sand materials, which are susceptible because of their ability to saturate prior to flood recession but their inability to drain as quickly as a rapidly receding flood. Rapid drawdown conditions and mass movement often occur in the Burdekin and Herbert Rivers, for example, where these soil conditions and flood characteristics are prevalent.

Surface Drainage and Mass Movement

Poor surface drainage that allows water to pond close to a bank can affect the stability of the bank by adding a surcharge that can promote unstable conditions, and by providing enhanced conditions for bank wetting and eventual saturation. Also, after flood events when bank materials may already be wet, ponded water on the surface provides an ongoing recharge that may retain higher than normal water levels, and so increase the potential for 'rapid drawdown' type mass movements.

Surcharge and Mass Movement

Streambank surcharge that may result from structures (such as buildings, pump stations and stabilisation treatments), machinery, ponded water, large trees and dredging spoil, increases load on a bank and may initiate mass movements. Instabilities due to surcharge are most likely to occur where the bank is already susceptible to mass movements because of its material properties.

Stream Modifications and Mass Movement

Stream modifications, such as stabilisation treatments implemented to improve bank stability, may actually exacerbate mass movement problems. This may occur when poor site investigations fail to identify the potential failure mechanism and its cause, or where treatments have been poorly designed or constructed. An impermeable structure, such as a rigid revetment that inhibits subsurface water from draining out of the bank and so encourages the development of rapid drawdown conditions, is an example of a poor stabilisation treatment.

Box 2.2 Subsurface Water Modelling

Computer modelling studies for the Herbert River Anabranch Bube study site (Chapter 4), have investigated how subsurface water movements in streambanks are related to streambank drainage configurations and to flood characteristics such as flood rise and recession. The studies analysed the inundation of the bank during flood rise, and drainage from the bank during flood recession for three typical streambank configurations (a homogeneous bank, a bank with drainage layer near the toe, and a homogeneous bank with a longitudinal drainage pipe). Figure 2.20 illustrates the results for flood rise and flood recession for each bank configuration. Only minimal differences in subsurface water levels occur in the different configurations during flood rise and the initial stages of recession from a bankfull saturation. However, during the final stages of flood recession, the longitudinal drainage treatment reduces water levels near the toe of the bank and therefore the length of the seepage face, and the drainage layer configuration has overall lower levels than the other configurations. Therefore, reductions in subsurface water levels and seepage face length through subsurface drainage treatment reduce the risk of mass movement during rapid drawdown.

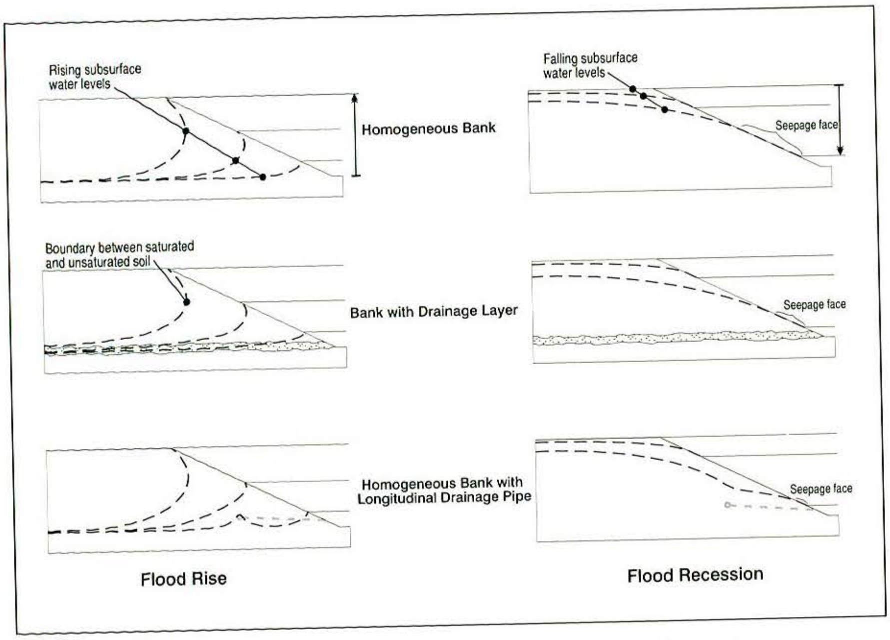


Figure 2.20 Illustrative subsurface water movements for flood rise and recession

2.6 Ecology

Streams and riparian areas contain unique habitats and have a high level of ecological significance. They are intimately linked to their catchments as they provide drainage and water supply, and therefore reflect or contribute to overall catchment health. Delineation of instream and riparian habitats can be difficult in some circumstances, although they each have special physical and biological characteristics. Instream habitats are dominated by aquatic processes, while terrestrial processes, modified by the presence of water, predominate in riparian habitats. Nevertheless, the two habitats are intimately linked physically and ecologically, and are essentially two parts of the same system.

Many of the streams in the region rise in or pass through National Parks or the Wet Tropics World Heritage Area and any activity along them (either inside or outside reserve areas) has potential to adversely affect their conservation values.

All the coastal streams in the region discharge into the Great Barrier Reef (GBR) lagoon, most of which is within the Great Barrier Reef World Heritage Area. The GBR environment has developed with these inputs and may well depend on them for nutrients, sediments, etc. But the Reef may be severely affected by major changes in those inputs, such as increased nutrient and sediment loads resulting from poor land and stream management, or decreased sediment loads resulting from impoundments, water abstraction and flow regulation. The international recognition of the World Heritage values of both terrestrial and marine environments in north-east Queensland acknowledges their special global importance and emphasises the need for special care in management of associated land and stream systems. As with any contemporary development or landscape modification, a precautionary approach is strongly advised when addressing stream management problems.

Stream ecosystems

Streams and associated wetlands and estuaries are vital components of most landscapes. Their physical and ecological roles are far more important than might be suggested by the proportion of the Earth's surface they occupy. They provide drainage for terrestrial systems, play a significant role in maintaining water quality and dry season flows, and may provide water in otherwise arid landscapes. They provide unique aquatic and riparian habitats, which may serve as ecological conduits from one region to another. They support unique species and higher taxonomic groups that are not found elsewhere, including platypus, freshwater crocodiles, and many species of fish, frogs, shrimps, mussels, insects and water plants. The plants and animals of fresh water bodies and estuaries are therefore of special significance in terms of both inland fisheries and ecological sustainability.

Streams are closely linked to their catchments by means of physical and chemical processes. Water quality depends to a great extent on the nature and use of the catchment - whether it is forested or cleared, whether it is used for grazing, cropping or urban development, and whether effluents from human developments are discharged into the water bodies. The existence of a normal assemblage of species indicates that their environment is relatively undisturbed, whilst deviation from the normal assemblage may signal degradation of water quality or habitat. The animals and plants may thus be used as monitors of environmental conditions both in the water and in the surrounding catchment. For example, the survival of some insect species may depend on good water quality while they are larvae, and on intact riparian vegetation when they are adults.

Understanding the major physical and ecological processes characteristic of fresh waters is a prerequisite for their successful management. Physical and ecological degradation in a stream may be caused by activities well upstream or downstream of a site and, whilst remedial action at that site may have short-term benefits, long-term solutions may only be gained by addressing the ultimate cause of the problem. Although it is relatively straightforward to address local problems, it is within the broader scale (catchment) that most processes operate and originate. Nevertheless, site-specific remedial action such as bank stabilisation is often a necessary part of a successful management strategy. The preferred bank stabilisation will allow maintenance of ecological diversity and function, and will be considered in the context of the different scales of physical and ecological behaviour of stream systems.

Habitats in north-east Queensland streams

A natural stream reach comprises a diverse array of habitats, each offering opportunities for colonisation by different plants and animals (Table 2.6). Figure 2.21 and Plate 2.9 show several typical stream habitats. Typically the habitats change gradually with progression from the uplands to the lowlands, with particular contrast between the source, transfer and deposition zones (Figure 2.1). In north-east Queensland the typical sequence of habitats from source to mouth is shown in Table 2.7.

In each region of the stream, habitat complexity depends on a variety of factors, including climate, gradient, discharge, depth, rock and soil types, surrounding vegetation, instream vegetation and grain size of the sediments. A single 100m reach may have a wide range of habitats, including weedy pools, waterfalls and cascades, silt, sand, boulder and bedrock substrata, beds of leaf litter of terrestrial origin, and woody snags.

Freshwater habitats also include riverine wetlands that are situated in intermittently flowing streams, or adjacent to streams on floodplains. They are usually flooded in the wet season, and are likely to have significant groundwater interactions. They are highly significant ecologically, have high conservation value and are poorly represented in conservation reserve systems. These habitats have suffered substantial loss and damage from urbanisation and agricultural expansion on tropical floodplains.

The diversity of habitats represented in north-east Queensland streams promotes high floral and faunal diversity. Many species are adapted to particular habitats: for example, species of mayflies (common insects, important as food for other animals) are variously adapted for living in fast currents, on rocks, in sluggish water, on waterfalls, and among weeds. Some species depend on bank vegetation to complete their life cycles, and many species depend on the input of riparian leaf litter as a food source.

Table 2.6 Common habitats in north-east Queensland streams and their physical and biological characteristics

Habitat	Characteristics	Typical plants and animals
Falls, cascades	Hard substratum, high velocity, shallow, often light.	Algae, moss. Specialised clingers. Many filter-feeders. Mostly insects.
Rocky riffles	Moderate to high velocity, turbulent. Variable rock size, patchy substratum. Sand, litter between rocks.	Algae, moss etc. Specialised clinging and swimming invertebrates, with some burrowers and litter-dwellers. Includes many insects, shrimps, some snails and worms. A few fish species, especially in lowlands.
Runs	Moderate velocity, non-turbulent. Substratum as for riffles.	Similar to riffles, but more fish species in lowlands.
Pools	Little or no current. Variable depth and substrate (rockier in uplands). Accumulated detritus.	Algae, rooted and floating vegetation in lowlands or larger systems. Riffle-type animals in rocky pools; otherwise many burrowing insects, worms, mussels etc.; many shrimps, snails; planktonic plants and animals; diverse fish fauna; tortoises, platypus.
Backwaters	No current. Usually silty, with organic detritus. Extensive rooted vegetation where substrate and light allow.	Rooted and floating plants submerged and emerging. Many animal species, especially burrowing insects, worms and mussels; snails and shrimps; dragonflies. Frogs; many fish in larger pools.
Sand	Rather abrasive, but aerated.	Algae. A few burrowers, mostly surface dwellers: shrimps, etc.
Silt	Richly organic, sometimes with low oxygen.	Many burrowing insects, and worms.
Leaf litter (instream)	Rich source of organic matter, and substrate which collects fine detritus. Distributed throughout small streams; may accumulate in large patches.	Specialised litter-feeders (insects, shrimps, some tadpoles); fine detritus eaters (insects).
Large woody debris (instream)	Provides solid stable substratum and cover, where often otherwise absent.	Used by numerous invertebrates as a substrate. Cover for fishes. Basking or vantage point for tortoises, kingfishers. Important breeding sites for fish.
Undercuts	Erosion under banks, often in deeper water. Often with large woody debris and roots.	Cover for many animals, especially shrimps, fish and platypus.
Roots	Usually under banks, provide relatively stable substrate with cover.	Colonised by many insect, shrimp and snail species.
Aquatic plants	May provide substrate for other attached plants and animals, and cover for free-swimming animals.	Colonised by many invertebrate species, including algae grazers which live on larger plants; cover and breeding sites for fish.
Open water	Flowing or still, shallow or deep.	Still waters with phytoplankton and zooplankton. All open waters with fish.
Tidal and saline reaches	Typically sandy or silty, shallow or deep.	Pool, silt, sand fauna. Freshwater elements decline and estuarine/marine forms increase with increased salinity. Typically mangroves at the margin and many species of shrimps, crabs, snails, worms and fish.
Riparian vegetation	Many roles. Provides cover and food for terrestrial animals (often a refuge from surrounding vegetation); cover for terrestrial stages of aquatic insects; cover for semi-aquatic vertebrates (eg. herons) and corridors between habitat patches.	Vegetation usually more diverse than surrounding land. Diverse invertebrate and vertebrate fauna, especially insects, reptiles, birds, mammals.

Table 2.7 Spatial sequence of habitats in north-east Queensland from source to mouth of stream

Zone	Characteristics of habitat
Source	Heavily forested with closed canopy; shallow, often low gradient streams; sandy or silty substratum; much leaf litter and small woody material OR high gradient with rocky substrate,
	Gradually increasing stream size with closed canopy; increasing gradient and current velocity; alternating pools and riffles; substratum varying from silt and sand through cobbles and boulders to bedrock; much leaf litter and small woody material.
	Broadening and deepening stream with breaks in canopy along long pools, waterfalls and some riffles; steep or stepped gradient; much of substratum silty or sandy with distinct rocky riffles and cascades; aquatic plants in pools and occasional large woody debris instream.
Transfer	Broadening of stream, open canopy, alternating pools and shallow sandy reaches; decreased gradient; much aquatic vegetation; erosion and stretches of deeper water on inside bends occasional riffles and cascades.
Deposition	Canopy directly influences only a small proportion of the stream; current velocity is slow; substratum is sand and silt, with possibly extensive beds of instream vegetation; mangroves along the estuarine section

Instream and riparian habitats are highly vulnerable to human disturbance. Human influence frequently tends to simplify habitats through, for example, flow regulation, sedimentation, vegetation removal, rock lining of banks and channel modifications (Plate 2.10).

Riparian flora and fauna

Riparian areas are those lands adjacent to watercourses and include the terrestrial vegetation adjacent to the stream (on the streambank and beyond), as well as the aquatic and semi-aquatic plants either within the stream environment or on the edge of the streambank. Riparian vegetation has a number of significant ecological values, which may include:

- providing habitat for a high diversity of terrestrial and aquatic plants and animals (mammals, birds, reptiles, amphibians, fish, insects and other invertebrates);
- providing drought refuges for many faunal species (eg. providing flowering plants for nectar-eating birds at times when surrounding woodlands are devoid of flowers);
- acting as a filter for sediment, nutrients and agricultural chemicals that are present in catchment runoff;
- protecting streambanks from erosion (particularly through the binding nature of roots in the soil);
- acting as a source of organic matter as food and of habitat (snags) for stream animals, and for the downstream ecosystem;

- providing shade, thus reducing temperature fluctuations and limiting the excessive growth of plant and algal populations;
- functioning as corridors for movement of terrestrial wildlife between habitat patches, especially in agricultural areas where most native vegetation has been cleared;
- influencing fluvial processes and channel morphology; and
- possessing an intrinsic conservation value in terms the unique plant and animal species and communities that occur in these areas.

Riparian plant communities play significant roles in the ecology of the stream environment, are essential for the conservation and maintenance of biodiversity, and are critical to the overall health of any catchment. Furthermore, the riparian plant communities of north-east Queensland are unique, containing many plant and animal species with significant conservation status. They are also, unfortunately, often poorly protected within the existing conservation reserve network. Furthermore, in many parts of the region, clearing has occurred to such an extent (often up to the high bank of streams and even to the waterline) that riparian communities have become extensively degraded as a result of vegetation removal, weed invasion, damage by cattle and inappropriate fire management practices.

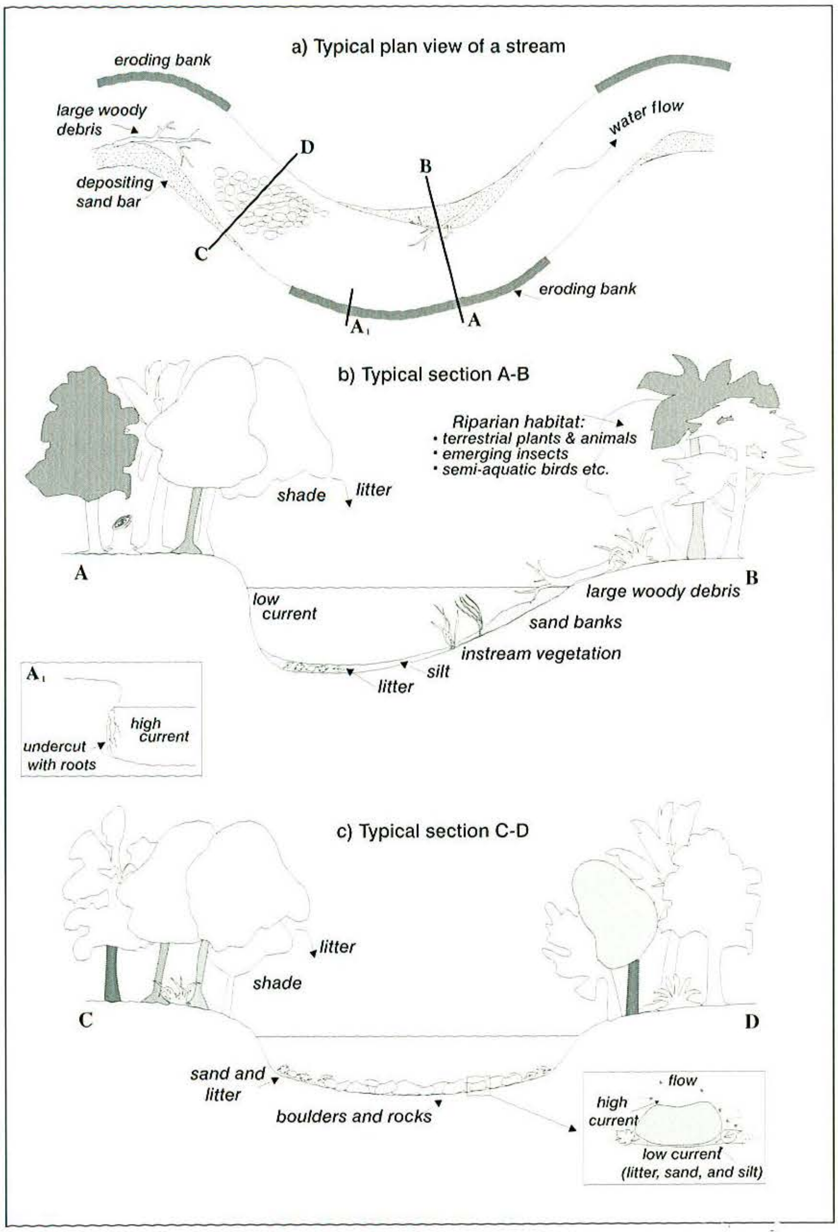


Figure 2.21 Typical plan view and cross-sections of streams

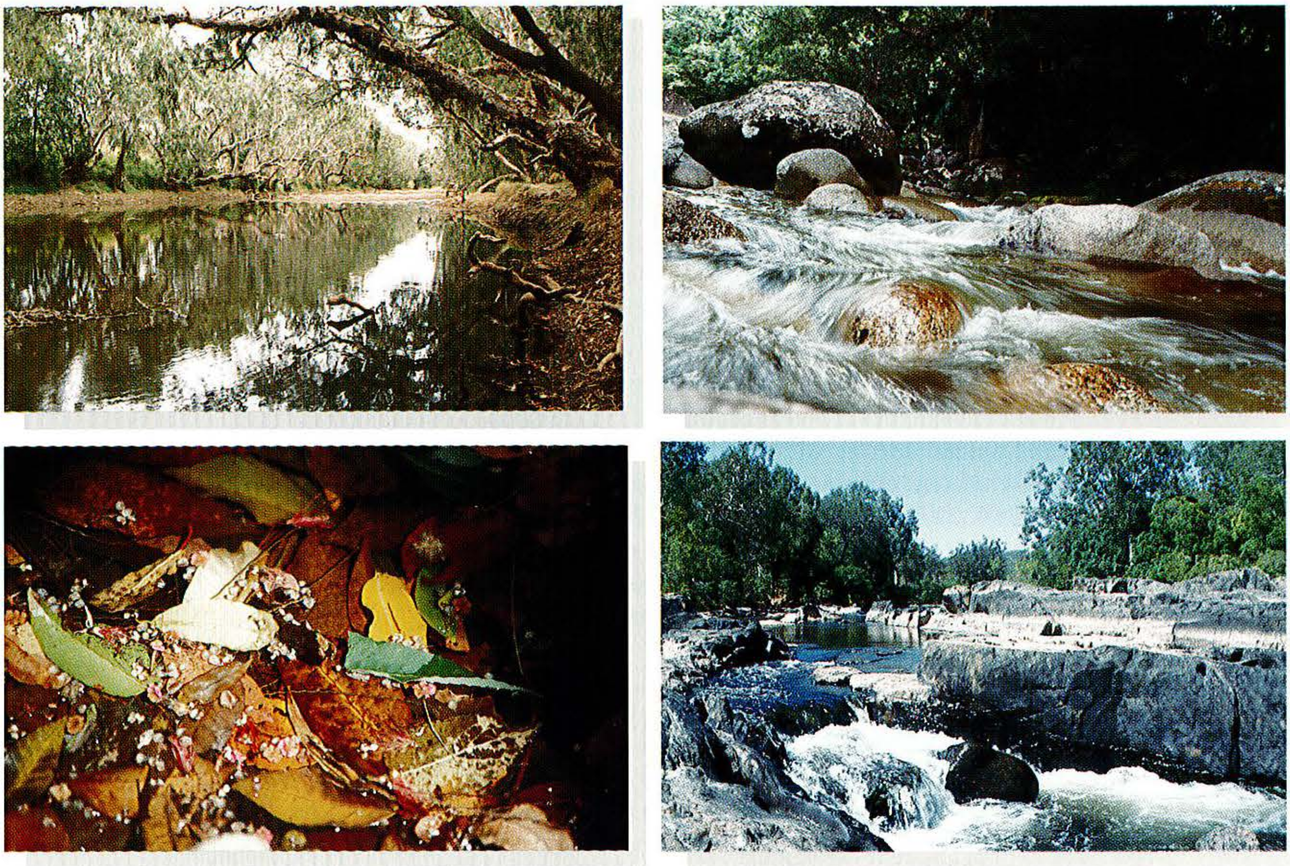


Plate 2.9 Typical stream habitats:
(a) Pools and backwaters with intact riparian zone; (b) Fast flowing rocky stream;
(c) Leaf litter from riparian zone; (d) Rocky cascades and healthy riparian vegetation

Plate 2.10 Degradation of stream and riparian habitats: (a) Riparian zone and waterhole degraded by weed infestation; (b) No riparian vegetation apart from weeds which clog the channel

It is therefore imperative that stream bank stabilisation techniques maximise the retention, use and/or rehabilitation of natural riparian vegetation. This is important where bank stabilisation offers an opportunity to rehabilitate and expand the riparian vegetation, and where intact riparian areas are threatened by bank instability or stabilisation works that would otherwise sever a continuous riparian strip. It is especially important in areas of undisturbed stream bank habitat to understand the structural and floristic diversity of riparian vegetation. This diversity is crucial, not only for the long-term sustainability of these plant communities, but also for the animal species that inhabit them permanently (eg. small mammals) and periodically (eg. birds). Stabilisation works should attempt to maintain or re-establish as much of this diversity as possible.

The progressive changes in the riparian plant community of a natural stream with increasing distance from the water's edge are important for ecological function of the stream and floodplain. Loss of this zonation weakens banks and makes them more prone to erosion (Raine and Gardiner, 1995). The toe of the bank is a critical area for stabilisation as this is where works often have a major impact.

The minimum width of the riparian zone necessary to maintain all its functions is an important issue for stream stabilisation and rehabilitation. Various recommendations have been made for minimum width; however, the required width is best determined from a site-specific ecological perspective and in the light of management objectives. Site-specific factors to be considered are the natural width of the ribbon of riparian vegetation, the relative importance of the site as a potential dispersal pathway (corridor), the form of the channel, high banks and levees, the type of vegetation, surrounding landuse, elements of the biota to be targeted, etc. Streambank stabilisation should include rehabilitation of the riparian zone at least to a width corresponding to riparian zones on contiguous parts of the bank.

Instream flora and fauna

In-stream plants (ie. aquatic and semi-aquatic species) may provide:

- a physical buffer between terrestrial and aquatic habitats that acts to bind soil together, reduce wave action and flow velocities and thereby dissipate energy at the stream edge, reducing erosion potential;
- improved water quality by assimilating nutrients and enhancing deposition of sediments;
- stabilisation of soil and sand by way of roots;
- food (detritus) and habitat for a wide range of animals, including invertebrates and fish;
- an intrinsic conservation value in terms on the unique plant and animal species and communities that associate with aquatic plants; and
- an intrinsic aesthetic value.

Many species of stream animals such as invertebrates (snails, worms, shrimps, insects, etc) and vertebrates (fish, amphibians, reptiles, birds and mammals) are found only in tropical Queensland (examples are shown in Plate 2.11). The invertebrate fauna of north-east Queensland upland streams is probably more diverse than any comparable fauna in the world, and lowland streams are also likely to have high diversity. Whilst all species contribute particular roles in the community, some have special interest for humans, and may have specific associations with streambanks (eg. platypus). Several important commercial and recreational fish species inhabit lowland streams (examples are barramundi, mangrove jack, mullet) and are likely to be affected by management works. These species feed on other stream animals and plants, and on riparian food sources such as insects and fruits that fall into the water. Like all ecological systems important interrelationships exist among species and the environment, and between species.

Ecological effects of streambank stabilisation works

The ecological effects of various stream stabilisation treatments on the bank and in the stream are listed in Appendix C. Stream managers should understand the consequences of different methods and assess the likely magnitude of effects in particular situations. The effects may be on individual species, whole communities, and on various ecological processes, and may influence the ecology of the system far upstream or downstream.

In pristine areas, streambank instability is not a problem because its progression and impacts are natural. In these situations, clearly, no intervention is necessary. The non-intervention option may also be preferred in non-pristine areas; however, this option is less likely to be acceptable because of the potential for damage to developed lands, buildings or infrastructure. Non-intervention may also be less acceptable ecologically as it may lead to damage to remnant habitats, such as vegetation patches or narrow riparian strips, and thereby diminish local conservation values. Nevertheless, the non-intervention approach should always be considered, and its costs and benefits (ecological, economic and social) weighed against those accruing from other treatments.

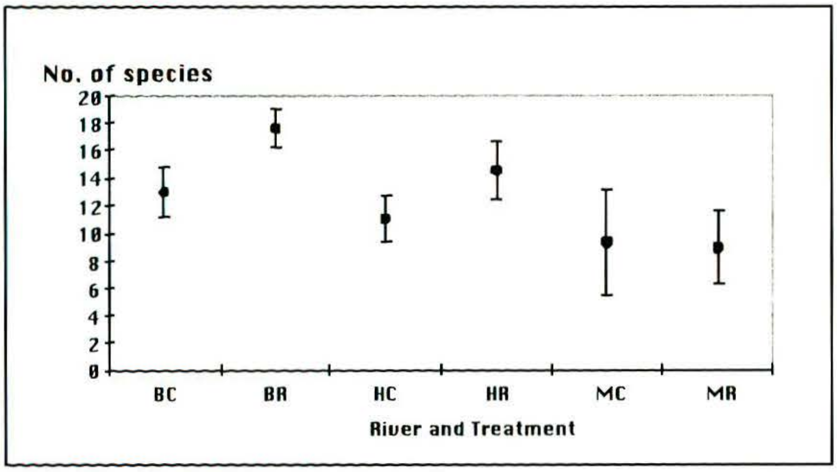
Where a site assessment indicates the need for intervention, the most ecologically-sound treatments should be considered first, with physical treatments (eg. rock) retained as a final resort, and then in combination with habitat-enhancing measures such as revegetation. The streambank should be considered as two adjoining habitats (the aquatic and the terrestrial) because some treatments may be much more benign in one habitat than in another. For example, 50m of concrete wall is only a tiny proportion of a 50km long stretch of bank, and any negative instream effects would be minimal; however, the impact on the bank may be to create a break in a continuous riparian corridor, which prevents the normal movements of animals. Clearly, all stabilisation treatments should consider riparian vegetation rehabilitation wherever possible.

Typical effects of loss of riparian vegetation are illustrated by the mammals collected at vegetated and rock sites on the Burdekin and Herbert Rivers (Table 2.8). Similar abundances of the two most common rodent species were detected at the vegetated site and the rock site, but the rock site had fewer species. The high abundance of *Melomys cervinipes* at the rock sub-site was unexpected, as this is typically a closed forest species. It is likely that individuals of this species may have been drawn from the forest by the baited traps. For this species, therefore, a short stretch of rock may not be a major barrier. However, the lack of several species from the rock sites confirms the expected unattractiveness of the rock as suitable habitat for most species.

The effect of rock revetment on the stream invertebrate fauna is illustrated by samples taken from rock and normal bank sites along several streams (Figures 2.22 and 2.23). There are few differences in *species number* between the stabilised streambank and adjacent natural bank, but there are significant differences in the *composition* of the fauna from natural and rock sites (Table 2.9). While the invertebrate communities from each habitat include many of the same groups of animals, their order of abundance is different. Thus, in well-established rock work there may be distinct, but not fundamental, differences from the natural situation.

Table 2.8 Small mammal trap returns for the Burdekin and Herbert Rivers (totals from 20 traps at each site, 3 nights of trapping)

River	Treatment	Species	Number caught
Burdekin	Control	*Melomys cervinipes*	2
	Rock	*Melomys burtoni*	1
		Melomys cervinipes	4
		Mus musculus	1
Herbert	Control	*Hydromys chrysogaster*	2
		Melomys cervinipes	28
		Perameles nasuta	3
		Rattus sordidus	14
		Rattus fuscipes	1
		Uromys caudimaculatus	2
	Rock	*Melomys cervinipes*	25
		Rattus sordidus	11



BC - Burdekin control
BR - Burdekin rock

HC - Herbert control
HR - Herbert rock

MC - Mulgrave control
MR - Mulgrave rock

Figure 2.22 Mean number of species at each rock and natural (control) site with 95% confidence intervals

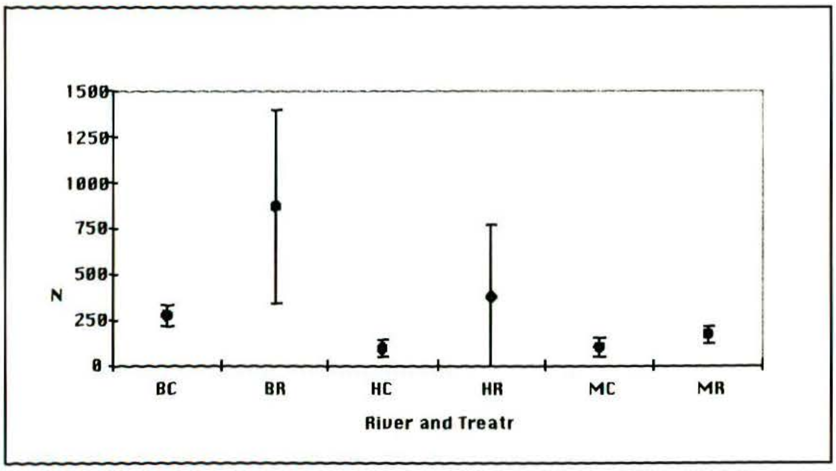


Figure 2.23 Mean number of individuals at each sub-site with 95% confidence intervals

Table 2.9 **Rank abundance of the six most abundant invertebrates collected from each rock and control site. Note similarities and contrasts between treatments (Rock) and natural (Control) sites, eg. preference of Baetidae and Caenidae (mayflies) for rocks**

	Burdekin River		Herbert River		Mulgrave River	
	Control	Rock	Control	Rock	Control	Rock
Atyidae		6	2	5	2	1
Baetidae		3		3		6
Caenidae	3	1	6	1		
Chironomidae	1	2	1	2	3	4
Corbiculina sp.	2	5				
Cyclopoida					1	3
Hydrobiidae	4					
Leptoceridae					5	
Oligochaeta					4	
Ostracoda				6		
Palaemonidae						2
Planorbidae			5			
Protoneuridae			3			
Thiaridae					6	5
Turbellaria		4		4		
Veliidae	6					
Zygoptera	5		4			

The instream effects of treatments are variable. Benefits may accrue from various structures, especially when they resemble natural habitats. For example, timber fences and piles may simulate natural snags, thereby adding to the diversity of habitats available (although chemically-treated timber may be detrimental to the biota). Groynes and embayments provide backwaters, which are special habitats required by many species of plants and animals. Even rock revetments provide some habitat values, especially when the toe is composed of large rocks. However, such treatments become less acceptable as the proportion of the streambank they occupy increases and the proportion of natural bank diminishes. Presently there are no data available to provide a guideline to the extent of bank modification that is acceptable. The extent would vary with the treatment (decreasing with the engineering 'hardness'). Preliminary data from the Herbert River suggest that, as a rule of thumb, the maximum ecologically-acceptable proportion of the bank of a particular section of stream to be treated with rock would be 20% instream, but less than 5% on the bank (unless accompanied by vegetation rehabilitation). An acceptable proportion for concrete walls would be close to zero, whilst the acceptable proportion for native vegetation treatment, would normally be 100%.

Condition of north-east Queensland streams

Extensive development in north-east Queensland has led to the degradation of many of its aquatic and riparian systems. The major impacts in this region have resulted from widespread land clearing and associated agriculture on the tablelands and the floodplain, especially for grazing and production of sugarcane. Even where clearing has not been extensive, poorly-managed cattle grazing has had severe impacts. Agriculture and grazing have led to destruction of the riparian zone and its vital functions, infestation by weeds, changes in channel morphology and drainage capacity, loss of natural predators on pests, introduction of novel habitats that harbour pests (eg. cane rat), and increased sediment and nutrient loads in streams. Furthermore, less extensive developments have had disproportionately large impacts - for example, tailings from mines have contributed large quantities of sediment and contaminants to streams, large organic loads have been discharged from sugar mills and sewage works, sand and gravel extraction has severely modified stream habitats upstream and downstream, and urban development has caused major change to water quality and habitat values.

While many upper catchments are protected in reserves and are in near-pristine condition, some are heavily affected. For example, many of the smaller upland streams rise in intact forest and sustain normal diverse ecological communities. However, others running across the Atherton Tablelands are in poor condition because of clearing to the streambank, weed infestation and soil erosion. Not one of the major lowland streams is in pristine condition, again because of the effects of agriculture and other activities. These issues are being addressed to some extent by more careful management at the catchment level, by better education, and by remedial and restoration works such as tree planting. However, the success of remedial action at a local scale often depends on large-scale issues. For example, intensive tree planting on the Barron River was destroyed by the build-up of floating para grass (an introduced pasture grass now infesting most northern waterways) during floods from Cyclone Justin in 1997. In this instance, riparian clearing, and contraction of the river channel because of the impoundment upstream led to weed infestation; during the floods the weeds lodged against young trees, impeding flow and causing the trees to be removed.

Despite these problems, most systems still support a diverse flora and fauna in the stream, but the riparian biota is severely degraded. Current work is assessing the extent of the degradation of riparian vegetation in the wet tropics. It is probable that outside of the reserves, less than 20% remains intact, and no major stream has a continuous corridor of native vegetation.

Plate 2.11 Typical fauna of north Queensland streams:
(a) Cormorants: fish-feeding birds which use riparian vegetation and snags as perches;
(b) Dragonfly nymph: a predator on other insects;
(c) Caddisfly larva which processes detritus on the stream bed;
(d) Diverse fish fauna;
(e) Oligochaete worm: common in soft sediments;
(f) Green-eyed frog which requires streams for breeding

2.7 Social, Cultural and Economic Factors

Urban, Agricultural and Industrial Development

Management of streams is needed because of the interactions between the stream system (its geomorphology, hydrology and ecology) and human developments. Effective management aims to maintain the range of human uses and natural functions of streams in perpetuity. The nature of the stream/human interactions dictates the management required. For example:

- a dam impedes the flow of a stream, so managers need to release water to maintain downstream ecological processes; and
- urban development on the banks of a stream, or extensive agriculture close to a stream will generate a need for managed bank protection.

Management may range from simple assessment, through regulation of the number of visitors to parks, to extensive engineering works. In all cases, protection of function is a prime goal which must be included with protection of land and/or infrastructure in any management plan. In the past, the level of management has been dictated largely by economic values. However, ecological values are increasingly incorporated in the assessment of options.

One of the primary management aims is to preserve the drainage function of streams. This role may be enhanced by straightening channels in urban or agricultural areas, and by constructing channels to drain wetlands. However, these activities not only severely damage natural stream profiles and processes, but also lead to more rapid drainage of water. This may have negative effects downstream because of the incapacity of the stream to deal with increased run-off volumes, which impacts on stream banks and threatens developments.

From an ecological perspective, the preferred management option is frequently to do nothing and let the stream take its natural course. However, this approach is usually not acceptable where infrastructure is threatened, where prime agricultural land might be lost, or where remnant vegetation is threatened

Some bank protection measures are employed to appease concerned landowners rather than as part of a sound management plan. Such measures, undertaken in a piecemeal fashion, often only delay the problem for a while, or simply transfer it upstream or downstream. Short-term political expediency is a fact of life and, whilst individuals' interests must be considered, a catchment-wide plan should ideally be adopted, with incentive mechanisms built in for landowners who are adversely affected by a 'do nothing' option. 'Do nothing', along with incentives, may well be the most economic option.

Recreation, Aesthetics and Amenity

The human values of streams are related to a variety of uses such as water supply, drainage, recreation, aesthetic and other amenity values. Some of these values are hard to quantify, but may contribute substantially to the well-being of the population of a region; others may have real dollar values, as in the utility of streams as tourism attractions.

Recreation is an important use of streams. It includes fishing, bird-watching and picnicking (the values of which are improved when human impact is minimised) and boating, which may or may not be affected by human disturbance. A natural riparian system provides good habitat for terrestrial and semi-aquatic species as well as shade, organic input and root/bank habitats for aquatic species. Natural flow regimes, too, provide the optimum conditions for the native biota. With careful stream management it is possible to sustain these values in most places, alongside development.

Aesthetics is an intangible value, but one which is strongly associated with streams. Simple appreciation of natural habitats and their biota is a 'quality of life' value, which figures highly as one of many individuals' basic needs. Even in areas of extensive agricultural development, such values may be retained at a significant level where agriculture is interspersed with natural habitat. At its minimum, this involves the retention of a substantial riparian ribbon in an agricultural landscape. A stream with a good riparian zone, running through an agricultural area, may retain many of its natural values and, therefore, its aesthetic appeal.

Archaeology, Traditional Use and Cultural Heritage

Aboriginal people of various groups have long inhabited north-east Queensland, and sites of Aboriginal cultural, historical and archaeological significance occur within the region. Some cultural sites associated with ancestral beings are now being documented, as are historical and archaeological sites which provide further important insights into Aboriginal culture and connections with the land. With European settlement in the late 1800s, many of these Aboriginal communities were gradually displaced, and massive disturbance of the coastal plain has left relatively few significant sites intact. Furthermore, the protection and preservation of the remaining sites is difficult for several reasons. First, strict conditions of secrecy surround Aboriginal cultural sites, with the locations of many entrusted only to community elders; second, in many catchments little research has been undertaken to identify these sites; third, State Government confidentiality requirements stymie attempts to gain information as to site locations and significance; and fourth, there is little effective protection of some of these sites.

In many of the region's catchments, mangroves and wetlands have been identified as a major focus of Aboriginal subsistence activity, and as being among the most archaeologically-significant areas. Because significant sites are unlikely to be preserved in cleared areas, efforts to preserve the remaining undisturbed wetland and mangrove areas may also serve to protect any surviving sites of Aboriginal significance. Aboriginal concerns and interests should be addressed as part of the Environmental Impact Assessment (EIA) of any development requiring the removal of or damage to wetlands. Such an EIA may be used to establish the existence and significance of Aboriginal sites. Aboriginal concerns and interests should also (at the very least) be addressed when proposed works affect a documented Aboriginal site and where investigations reveal that a site of significance to Aboriginal people is being affected. In all cases the significance of the sites to Aborigines should be respected, and appropriate protective measures or solutions resolved through consultation. The appropriate government agency should be consulted to establish whether Native Title claims exist over the proposed works site.

Management Planning

The stream manager should attempt to consider all issues and make decisions based on a strategic, not reactive, management plan. While quantifiable economic issues tend to dominate, they should not overrule major ecological or human amenity values. Additionally, in incorporating all values in the decision process, true economic value should be assessed. The supposed productivity of a piece of land should be assessed in terms of its long-term productivity (discounting subsidies); costs of management works should include not only actual costs of materials and labour, but also predicted costs of subsequent loss of land upstream or downstream, and costs of works in those places. Such considerations should not be done piecemeal, but form part of a stream or catchment strategic plan. Any proposed management work should be preceded by a formal analysis of the type 'is it worth it?' as well a 'what impact might it have?'.

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Chapter 3 - Project Planning and Design

Summary

- For sustainable stream management, stream managers should understand stream processes, be aware of the human use of the stream and the human pressures affecting the stream, and develop a range of management objectives relevant to the various stream users.
- Even the best designed stream stabilisation and rehabilitation works can fail to deliver the desired results unless the whole process is well planned and well implemented.
- The ten-step process for stream stabilisation and rehabilitation presented in this Chapter guides stream managers from problem definition, through choice of objectives, to determination of the strategy or treatment solution.
- The planning, design and implementation process for a project can be grouped into five sequential phases, leading from concept, through feasibility and implementation, to monitoring and review.
- Although directed primarily towards streambank stabilisation problems, the ten step stream management approach can be used to address a range of associated issues and problems, such as habitat degradation and reduced water quality.
- An interdisciplinary approach is important for successful remediation. The stream manager should coordinate field and office studies and acquisition of data between the disciplinary groups.
- The preferred stream management approach considers stream management problems and remediation objectives for the reach/site within the context of the whole stream catchment.
- Site assessment activities should examine the stream reach/site within the context of the stream catchment, and are most effective when phased in the same manner as the project phases.
- Consultation with stakeholders (the client, government agencies, local authorities, landholders and community groups) is an essential part of stream stabilisation and rehabilitation projects.
- A best practice checklist for stream stabilisation and rehabilitation is presented in Appendix D.

3.1 Planning and Design Framework

While it is desirable that stream managers take a *proactive* approach to prevent stream management problems occurring, a *reactive* stream management approach is sometimes necessary to respond to existing or emerging problems in a particular reach/site of a stream. Either way, sustainable stream management is founded on:

- understanding of stream processes;
- awareness of the present and anticipated human use of the stream;
- knowledge of the human pressures affecting the stream; and
- a range of management objectives that reflects the different needs and expectations of the various users of streams and their environs.

The preferred stream management approach considers the potential or existing problems and the objectives for the reach/site within the context of the whole stream catchment. All physical, biological, economic, institutional, political and social factors are considered.

A straightforward, yet rigorous process should be used to ensure that the broad range of issues is appropriately addressed in developing stream remediation programs. The recommended approach for stream stabilisation and rehabilitation projects presented in this Chapter leads from problem definition, through choice of objectives, to determination of the strategy or treatment solution.

The recommended conceptual framework for the planning, design and implementation of stream remediation programs (Figure 3.1) comprises the following elements:

- the human use or **utility**(ies) of the stream that may be affected by the problem (eg. water supply, aggregate extraction, recreational use, conservation value);
- the **pressures** that may be related to the problem, including **direct** pressures such as flow regulation or presence of exotic species, and **indirect pressures** such as landuse and pollution;
- the nature of the **problem** (eg. streambed instability, riparian habitat degradation or degraded water quality);
- the **stream processes** that drive the natural behaviour of the stream and provide the link between human activities, pressures, problems and remedial actions;
- the **objectives** for remediation programs, including, for example, physical stability, utilities to be protected, environmental protection and rehabilitation, and socio-economic constraints; and
- the range of **strategies and treatments** that meet the desired objectives (eg. streambank stabilisation, catchment management, stream restoration and flood mitigation).

The interrelationships between the elements shown in Figure 3.1 are illustrated in the example in Box 3.1. Problems may result from the effects of stream processes on human utilities, the effects of human pressures on stream processes, or the accelerated effect of human pressures on stream processes which in turn affect human utilities. The stream management objectives to deal with these problems must relate to the problem itself, the relevant pressures, and the utilities. Strategies and treatments are directly related to the objectives and, as with the objectives, must be established within the framework of the stream processes.

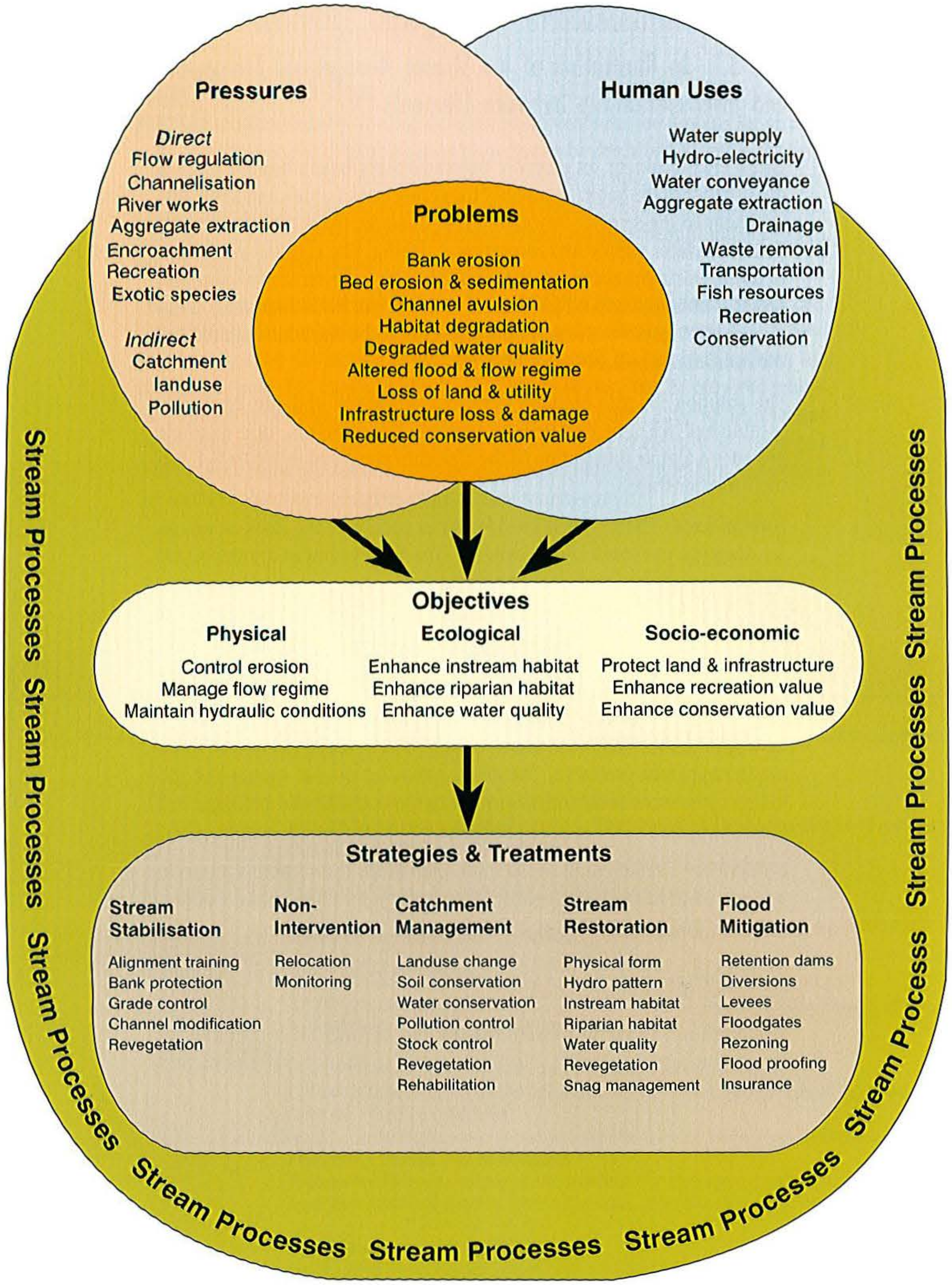

Figure 3.1 Conceptual framework for stream stabilisation and rehabilitation
The examples used are indicative only, and do not represent the full range of variables for each factor

Box 3.1 An Illustration of the Stream Management Framework and Interrelationship between Elements

Cattle encroachment on a poorly vegetated streambank has led to local disturbance of the bank, apparently triggering bank failure, and delivering sediment to the stream. Downstream of this site, the stream is used for domestic water supply and recreational fishing. The riparian vegetation in the downstream section of the stream has high conservation value and provides essential habitat for a rare species of bird, but is degrading. Local stream managers wish to solve the problems at the site whilst addressing the utilitarian needs of the landholder.

The solution for this problem is fairly elementary, and can be readily established without detailed evaluation. Nevertheless, this example provides a simple illustration of the elements presented in Figure 3.1 and their relationships.

Human uses - The stream is used for water supply for the stock as well as for domestic purposes and by wildlife. The fish resources are important and the stream has high conservation value.

Pressures - The principal pressure is the direct pressure of the cattle grazing, although landuse in the catchment may change sediment and flow regimes and pollute the stream.

Problems - Bank erosion, instream sedimentation, degraded riparian and instream habitat, degraded water quality, and reduced recreation value are the apparent problems. The direct pressures on the stream and the indirect pressures in the catchment bring about the stream management problems by way of the **stream processes** and their effect on human utility.

Objectives - Stabilisation of the bank (physical), restoration of riparian and instream habitat (ecological), and protection of human uses within available budgets (socio-economic).

Strategies - Likely to include streambank stabilisation and, perhaps, catchment management measures.

Treatments - Likely to include fencing out of stock with provision of alternative watering points, bank revegetation, habitat restoration, and catchment-scale measures to reduce erosion and runoff.

3.2 The Planning, Design and Implementation Process

Project Phases and Steps

The recommended planning, design and implementation process for stream stabilisation and rehabilitation projects can be described in terms of a ten-step process, which is detailed in the following section. The ten-step process does not provide a cookbook solution for stream management, but it does provide a consistent approach by which to address stream management problems and to design suitable remediation.

The steps can be grouped into five readily identifiable project phases: (1) concept, (2) feasibility, (3) implementation, (4) monitoring and maintenance, and (5) review (Figure 3.2). The distinction between the phases will be less well defined for smaller projects. For example, the feasibility phase may not be required where the solution is obvious, and the detailed design component may not be relevant where only non-structural solutions are adopted. Nevertheless, it is suggested that the sequential phases and steps be followed as they are important in meeting the broader objectives of sustainable stream management.

Phases	**Steps**	**Description**
Concept	Step 1	**Identify and Describe the Problem** Identify the problem(s), describe the potential consequences of the problem, and establish the associated level of risk
	Step 2	**Identify Relevant Utilities and Pressures** Identify human uses (utilities) that are affected by the problem, and direct and indirect pressures that may contribute to the problem
	Step 3	**Examine Stream Processes and Determine Causes** Examine relevant hydrological, geomorphological and ecological stream processes, and determine the causes of the problem
	Step 4	**Define Remediation Objectives and Assessment Criteria** Specify objectives to address the problem, establish criteria for assessment of the treatment against these objectives, and define constraints
	Step 5	**Identify Remediation Options and Develop Concept Designs** Undertake a preliminary assessment to identify a short list of remediation options that may meet the specified objectives
Feasibility	Step 6	**Feasibility Design and Evaluation** Prepare preliminary designs of the remediation alternatives and evaluate these alternatives against established criteria, from a physical, ecological and socio-economic perspective
	Step 7	**Decide on Remediation Program** Decide on the remediation option that best meets the adopted criteria, values and constraints for the project
Implementation	Step 8	**Detailed Design and Implementation** Prepare detailed designs for the chosen remediation option, and implement the remediation program.
Monitoring & Maintenance	Step 9	**Monitor and Maintain** Monitor the performance of the program against the established objectives and undertake maintenance to ensure compliance
Review	Step 10	**Review Project** Examine the treatment performance, and review the success or failure of the project to assist in future stream management

Figure 3.2 Project phases and the 10-step process

Application of the Ten-Step Process

Although the procedures outlined in these guidelines are directed primarily towards streambank stabilisation problems, the conceptual framework and the ten step process can be used to address a wide range of stream management issues and problems. In assessing a stream for bank or bed instability, the stream manager may encounter a number of these other problems (such as habitat degradation, water quality problems, flooding, or loss of land and recreation values), which may be a direct consequence of the instability or may be a problem in its own right. Where the instability and other problems have the same cause, the stream manager will solve a number of problems and limit further degradation by addressing this cause. Where the problems have different causes, an integrated solution that addresses a number of problems and causes may be necessary. Failure to address the associated problems may in time aggravate the instability and contribute to further degradation of the stream.

Project Team

Successful remediation of stream stabilisation problems requires an interdisciplinary approach. For smaller projects, the stream manager (Project Officer) will need to consult with practitioners from relevant disciplines. A multidisciplinary team, comprising engineers, geomorphologists, ecologists and others, is essential for larger projects.

Team members will benefit if they communicate frequently and undertake joint site visits wherever possible to ensure that relevant issues are not overlooked, and to share insights and gain improved understanding of how the various disciplinary matters fit within the broader requirements of the project.

The Project Officer, who may be a river improvement trust engineer, local authority environmental officer, river management consultant etc, may take the major role in smaller, straightforward projects, seeking specialist advice as required, and maintaining appropriate stakeholder consultation. In larger or more sensitive projects the Project Officer may be the coordinator of the multidisciplinary team, briefing specialists within each of the appropriate disciplines, arranging for acquisition of much of the general data, and coordinating joint site visits, office meetings and stakeholder consultation.

Documentation

Documenting all the assumptions that are made and all the analyses that have been undertaken during the planning, design and implementation process is encouraged. This facilitates program evaluation and is a means of transferring knowledge between practitioners.

Site Assessment

Site assessment is an integral part of the planning, design and implementation process in that it helps stream managers and teams working on stream remediation understand the characteristics of the site. This assessment assists in defining the problem, understanding stream processes, analysing the causes, and developing and evaluating alternative solutions. Assessment requirements are very site-specific and no prescriptive guides can be given to suit every situation. Nevertheless, Table 3.1 provides a framework for site assessment and an indicative list of the stream characteristics which may need to be examined.

The recommended site assessment framework uses a spatial hierarchy to examine stream conditions and processes for the reach/site (fine) scale within the context of the stream catchment and the section (broad) scales. Detailed procedures for determining these characteristics are beyond the scope of these guidelines, but the general approach for each of the disciplinary areas is described below.

The site assessment activities need to be 'phased' in the same way as the project phases outlined above, notably concept, feasibility and implementation. The concept phase needs to address the problems and seek to understand their causes, whereas the feasibility phase needs to examine and design the remedial treatment. The implementation phase, if adopted, may involve more detailed or supplementary investigations related to design of the remedial program.

The phased approach can minimise assessment costs early in a project, which is particularly important when the project does not proceed to implementation. A phased assessment can provide information at the most relevant time in a project, therefore minimising the likelihood of having to repeat site visits and assessments that were undertaken before the full requirements of the assessment were known. Likely phasing of the site assessment activities within each of the disciplinary areas is described below.

Table 3.1 Framework for site assessment

Scale	Characteristic	What to assess
Catchment	Physiography	Size, orientation, topography
	Hydrology	Rainfall - intermittent, perennial,
	Ecology	Terrain, terrestrial habitats, instream habitats
	Human activity	Dams, landuse, stream uses
Stream section	Stream zone	Estuary, floodplain, transition, upland
	Channel form	Nature of meanders (braided, anastomosing, straight)
	Channel history	Avulsion, stage of evolution, stability
	Hydrology	Bankfull flow capacity, flood frequency, flow regime, distributary flows, stream/floodplain interaction
	Instream and riparian habitats	Riffle/pool sequence, velocity of current, riparian integrity, instream vegetation, terrestrial vegetation
	Human activity	Agriculture, grazing, mining, urban development, stream modifications
Reach/site	Channel geometry	Planform, bed and bar form, gradient, cross-section
	Channel history	Stability, aggradation, degradation, rate of change
	Hydrology	Stage discharge, rate of rise and recession, flood duration
	Hydraulics	Flow depth, velocity, turbulence, currents and waves
	Bank surface flow	Drainage inflow, flood outflow, depth, velocity
	Bank subsurface water	Flood inflow, drainage outflow, pressures, water levels
	Water quality	Turbidity, temperature, pH, nutrients, metals
	Sedimentology	Rating curve, textural characteristics, distribution
	Erosion	Scour, slumping, overbank erosion, headcut
	Bank soils	Stratigraphy, properties, permeability
	Riparian habitats	Morphology, complexity, integrity, vulnerability, cover and shade, native vegetation, organic matter and snags, barriers, riparian fauna, weed infestation
	Instream habitats	Morphology, complexity, integrity, substrate, streamflow, water quality, native vegetation, habitat utility, fish passage, aquatic fauna, weed infestation
	Land tenure	Freehold, leasehold, Native Title
	Human activity	Agriculture, urban, aggregate extraction
	Human use	Water supply, navigation, recreation, aesthetics, amenity
	Conservation	Naturalness, habitat integrity, rare and endangered species, connectivity

Stakeholder Consultation

Consultation with stakeholders (the client, government agencies, local authorities, landholders and community groups) is an essential part of stream stabilisation and rehabilitation projects. Stakeholder consultation may occur throughout each of the project steps but is particularly important in the concept phase.

Consultation may be undertaken informally, but a formal component will ensure that the affected parties are given an opportunity to have input. This formal component, recommended even for small projects, may be limited to an arranged site inspection with the landholder, or a briefing with agency or community representatives (eg. catchment group, local authority, Department of Environment). Larger projects may entail more extensive consultation, including attitude surveys, workshops and briefing sessions.

Stakeholder consultation assists with:

- defining the scope of the project;
- identifying and understanding the problem;
- obtaining information on the history, magnitude and consequences of the problem;
- determining community expectations of the utility of the stream;
- identifying the history, magnitude and results of pressures on the stream;
- access to historical flood and channel change records to assist in the analysis of stream processes;
- input to the development of objectives for remediation;
- feedback about concept designs and review of objectives;
- development of and decision on the adopted scheme; and
- review of project performance and maintenance requirements.

Data Acquisition

The site assessment program will contain some specialist activities and data acquisition that must be undertaken by trained geomorphologists, hydrologists, ecologists or geotechnical engineers. Notwithstanding this, much of the general information obtained for the project, and some that is obtained by individual specialists, will meet multidisciplinary needs.

Aerial photographs, topographic surveys and anecdotal data, for example, will apply to all disciplinary areas and will be used in many of the steps.

General information, such as aerial photographs and preliminary surveys, will be acquired in the concept phase. The principal site surveys for survey control, topographic and cadastral data will normally be undertaken in the feasibility phase, but some construction survey control may be undertaken in the implementation phase.

The Project Officer will need to sequence data acquisition activities and analyses to ensure that results are available for project team members at the appropriate time, thereby avoiding duplicated effort.

The general information to be collected may include:

- aerial photographs;
- remotely-sensed images;
- photographic records of the site;
- video photography;
- topographic mapping at catchment, floodplain, reach and site scales;
- stream channel longitudinal sections;
- channel cross-sections;

- cadastral data and land tenure;
- soil and surficial geology maps;
- vegetation mapping;
- landuse in the vicinity of the problem, extent of clearing;
- proximity and type of infrastructure;
- construction plans and records of previous stream management activities;
- historic field inspection reports;
- site entry and exit points for construction and maintenance;
- location of stockpile areas, access and haul roads;
- temporary and permanent stream crossings;
- previous studies relevant to the site, to the stream or to the catchment;
- scientific publications and other references;
- historical data from newspapers and other publications; and
- anecdotal information and local knowledge from stakeholders and others.

Geomorphological Assessment

Much of the geomorphological investigation will be undertaken in the concept phase in order to establish the spatial and temporal significance of the problem and to understand the stream processes and the cause of the problem. Analysis of the effects of various remediation schemes is undertaken in the feasibility phase, and may include a significant geomorphological component.

Detailed qualitative and quantitative measurements and observations are useful for critical reach and site locations. A geomorphologist needs to be consulted.

Geomorphological investigations may be conducted at various levels of detail, the level depending on the scope and objectives of the particular study. They may include:

- historical channel change (size, location, rate, erosion, degradation, aggradation);
- channel planform;
- stream hydrology (bankfull flow capacity, stage discharge curve, flow frequency curve);
- hydraulic characteristic of stream channel (gradient, width, depth, obstructions, bars);
- bed and bank materials;
- sediment rating curve, textural characteristics and distribution of the sediment load;
- modifications to natural stream condition;
- underlying causes of problem; and
- likely response of stream to intervention or non-intervention options.

Hydrological Assessment

Hydrological and hydraulic studies will commonly be undertaken in both the concept and feasibility phases of a project. The concept-level investigations will usually be related to flood and regular flow characteristics (eg. frequency, duration, velocities) that affect the problem at the site. Feasibility investigations will be directed towards flow characteristics, performance and loading on structures. Preliminary office studies will generally be undertaken to compile maps, gather historical information and examine catchment characteristics before undertaking field investigations.

Hydrological and hydraulic studies may include:

- collation of historical and recorded flood data (flow rate, levels, velocities, inundation, duration, rise and recession rates);
- historic and recorded rainfall data;
- tidal effects;
- flood frequency analyses, flow duration curves, flood hydrograph;
- flow discharge estimation;
- estimation of velocities, depths and directions of flow;
- upstream and downstream flood levels and afflux (increased water levels) at structures;
- observations of flow patterns; and
- environmental flow requirements.

Geotechnical Assessment

Preliminary geotechnical site assessments will usually be undertaken in the concept phase to determine the cause of bank instability (scour or slumping). The principal geotechnical site assessment will be undertaken in the feasibility phase to determine excavation, foundation and loading conditions for relevant structures, as well as safety issues and construction limitations. Some specialist field testing and laboratory testing may be conducted in the implementation phase when the type and final configuration of any structures are being finalised.

Geotechnical investigations have a large field component, and need to be carefully coordinated with the geomorphological field work. The following activities may be incorporated:

- site drilling, test pits, *in situ* testing and sampling to determine soil strata, types and characteristics;
- laboratory testing (soil type, strength, cohesiveness, moisture content, permeability);
- examination of subsurface water conditions;
- examination of the extent of failure and evaluation of the likely failure mechanism;
- assessment of the likelihood of subsequent failures;
- assessment of the safety of the failed site;
- examination of construction method; and
- structure load-testing (piles, foundations).

Ecological Assessment

Specialist input from an ecologist is beneficial in the concept phase to assess the ecological significance of the site and project, and to determine the scope of the ecological work that is required. Detailed site investigations (eg. habitat assessment or flora and fauna surveys) may be deferred until the feasibility phase if the information is not critical to the initial choice of remedial options.

The purpose of describing ecological site characteristics is to assess the impact of the problem/failure on ecological processes and values, and to provide input to the selection of appropriate treatments for the problem. Whilst attention will often focus at the site of the immediate problem (slump, erosion, etc.), a broad view is necessary to assess the importance of the problem in relation to the overall stream characteristics. Therefore, ecological assessment of a site includes description of the surrounding land, the riparian zone and instream characteristics, at scales ranging from the immediate vicinity of the problem (usually tens of metres), through the stream reach (100 to several 100 metres), to the stream section (tens of kilometres) and, possibly, the catchment. The level of detail required will decline with the increase in coverage of the assessment.

Ecological assessment may include field studies to measure, sample and record data, laboratory studies to test samples; and desk studies to collate and analyse data.

The scope of the investigation will depend on the type of problem and ecological system to be addressed. Extensive ecological surveys will normally be required in complex situations but this is not always the case. For example, where the surrounds of a bridge are damaged, assessment of instream habitat may be irrelevant because the remedial action is dictated by the present bridge structure and by accepted construction techniques. Similarly, a bank slump in virgin native forest may require little further than the comment 'native forest: no threat to infrastructure', which would normally dictate that no further action be taken.

Many situations will require specific knowledge for adequate assessment. Whereas anyone can estimate the width of the riparian vegetation, and anyone can distinguish between grass and trees, an ecologist would normally be required to provide a comprehensive vegetation assessment, in the context of the reach and section, and to distinguish between native and weed species. While vegetation on a particular bank may be described as 'lush', if it comprises leucaena, bamboo and tobacco plant, its ecological values are low. An ecologist would also be required to accurately assess aquatic habitats and their fauna.

The methodology essentially involves an assessment of habitat, as habitat is the main determinant of conservation values. The focus is, therefore, on vegetation structure and habitat complexity, and comparisons with contiguous terrestrial, riparian and instream areas. Identification of plant species is necessary to identify weed infestation, and to identify suitable species for rehabilitation. Faunal surveys may be required in situations where the fauna is poorly known, and ecological values of habitats need to be determined.

To set the site in its broader geographical context, ecological assessments need to include a brief description of the site, its habitats and their values, and the problem. Values are not static: poor riparian value can be converted to high value following stabilisation and rehabilitation work, and threatened habitat may be protected by intervention. For example, stabilisation work was implemented at the Stewart Road site on the Mulgrave River (Case Study 1) to protect native riparian forest and farm land. Normally, if only the forest was affected by the bank erosion, the response would be to let nature take its course; however, the forest in this case is a remnant patch with possibly high conservation values (habitat, connectivity) and the non-intervention option would see the patch disappear completely.

Project Appraisal

A number of alternative schemes will commonly be considered before deciding on a remediation program to address a stream stabilisation or rehabilitation problem. The alternative schemes will have different economic, environmental and social costs and benefits, and often must be evaluated against a range of objectives across a number of disciplinary areas. These appraisals are commonly undertaken through the evaluation and decision steps (Steps 6 and 7) of the ten step process. Various appraisal methods are available, ranging from conventional benefit-cost analysis to environmental impact assessment. While the issues are introduced here, the user is advised to refer to other literature in order to apply these methods.

Whatever approach is used, project appraisal has little value unless judgement is applied in the interpretation of data. The appraisal process is not a replacement for this judgement, but merely an aid. Project appraisal provides a focus for an interdisciplinary team to hear and understand various professional views, allow interdisciplinary trade-offs to be considered, and present a comprehensive evaluation to decision makers.

Benefit-Cost Analysis

Stream stabilisation or rehabilitation projects incorporate tangible costs and benefits (eg. implementation costs, value of damage avoided through loss of land) as well as intangible benefits (eg. reduced disruption, long-term improvements in environmental condition). A number of difficulties and shortcomings are experienced in the application of conventional economic analyses to these projects. Benefit-cost analysis, for example, often only accounts for costs and benefits readily measured in monetary terms. Unpriced costs and benefits must also be considered by the decision-maker if an objective appraisal is to be undertaken.

Benefits that accrue from stream stabilisation or rehabilitation projects can be classified as either market benefits (valued at market prices), or non-market benefits (described but not normally valued). Market benefits are usually savings resulting from the prevention of loss and damage for such things as:

- value of land saved from loss or isolation;
- value of increased production;
- value of avoided flood or erosion loss or damage to assets such as roads, rail lines, bridges, buildings, fences, stock;
- value of access difficulties prevented; and
- value of increased or retained recreational or tourist opportunities.

Market prices are rarely established for non-market benefits. Although they may sometimes be valued in monetary terms to add to market benefits, non-market benefits are most commonly considered by decision-makers without values being assigned. Non-market benefits are usually derived from a reduction in loss associated with, for example:

- soil and pollutant runoff reaching waterways;
- sedimentation and resultant benthic habitat loss;
- ongoing bank instability and loss of riparian land;
- habitat and food source loss for riparian and instream species;
- invasion of banks and stream edges by weed species following loss of riparian vegetation;
- loss of potential wildlife corridor/habitat provided by remaining riparian vegetation;
- loss of drought refuge for terrestrial wildlife as riparian habitat is replaced by weeds;
- degradation of present stream aesthetic and recreational values; and
- disruption to the community resulting from loss of road access.

Rapid Appraisal Method

The Rapid Appraisal Method (Read Sturgess & Associates and Ian Drummond & Associates 1992) allows consideration of market and non-market aspects in the evaluation of economic benefits of stream management projects. This method not only provides for a rigorous evaluation of alternative schemes, it also provides decision-makers with (i) a basis for making decisions on whether or not a program should proceed; (ii) information to help them assign priorities to the works; and (iii) a foundation for deciding who should share in the costs of the works program. It is designed to be used by experienced economists and stream managers, and will always involve significant judgement. Those undertaking the evaluation need to understand stream processes, and have access to historical data on the river system to allow quantification of these processes.

The Rapid Appraisal Method (RAM) compares various scenarios about the future with and without a stream stabilisation or rehabilitation program, and equates benefits to the loss or damage avoided if the program is implemented. Management strategies are developed appropriate to the various scenarios, and an evaluation of economic, environmental and social consequences is undertaken over the life of the project, based on an understanding of geomorphic processes.

Wherever possible, quantifiable (market) benefits of stream stabilisation or rehabilitation projects are allowed for in dollar terms in the Rapid Appraisal Method. Where market values are not assigned, all unvalued (non-market) benefits need to be listed so that a decision can be made with full information.

The present values of benefits are calculated using standard discounting procedures to establish net present value for an adopted life of the project. The period over which to evaluate stream management programs is an arbitrary choice, but a period of 30 years is commonly adopted, as most programs would have reached reasonably steady state in this period of time.

Multi-Criteria Decision Making

Multi-Criteria Decision Analysis (MCDA) provides a method for considering several conflicting objectives in the evaluation and decision steps. MCDA assists decision-makers choose between options by applying a set of evaluation criteria, and ranking the options according to how well they satisfy the adopted criteria. It can take account of different points of view by varying the weight applied to the criteria. Major benefits include a more rational structuring of the decision-making process and a better understanding of different options, and the effects of divergent social values (including those from the broader community) upon their evaluation.

The appraisal process identifies key issues to be considered in decision-making and recognises the importance of the decision-making process rather than merely arriving at the correct decision. Decision-making incorporates subjective decisions that depend on various value systems and objectives, and MCDA provides a framework within which the effects of uncertainties and different values can be evaluated and explored, integrated and analysed, so as to present the information in a manner that is useful to decision-makers.

MCDA is suitable for complex problems with large amounts of information but is not normally required for simple projects with a limited number of options or objectives.

3.3 The Ten-Step Process

STEP 1 Identify and Describe the Problem

Scope

- **identify and describe the streambank or streambed instability problem in terms of:**
  - **its physical, ecological, geomorphological and socio-economic characteristics;**
  - **the potential consequences associated with the problem;**
  - **the level of risk associated with potential consequences; and**
  - **any associated problems.**

Purpose

To produce a complete and accurate description of the nature and extent of the problem that initiated the investigation, as well as any related problems.

Description of the problem and knowledge of utilities and pressures from Step 2 are essential for design of remedial actions. Incorrect or incomplete identification of the problem, or failure to identify supplementary problems, could lead to inappropriate responses that do not adequately address the real stream management problems.

The range of possible stream management problems has been introduced in Chapter 1. More detailed descriptions of the problems are given in Appendix B.

Description of Problem

In describing the problem, answer the following questions:

- What are the geomorphological characteristics of the problem? (eg. geomorphologically unstable reach, erosion of outside of meander bend, rate of change, meander cutoff, vegetation-stabilised instream bars);
- What is the classification of the instability? (eg. slump, tunnelling, fluvial erosion, head cutting, inflow erosion, avulsion);
- What are the ecological characteristics of the problem? (eg. loss of riparian vegetation continuity, sedimentation of instream habitat, infestation with exotic species);
- What are the socio-economic characteristics of the problem? (eg. loss of land, increasing risk of major channel change, transport infrastructure threatened, scenic values degraded).

Consequences of the Problem

Examples of the consequences of stream instability are:

- loss of land (rate of loss, ownership of land, impact on owner, value of loss);
- degradation of habitat (sediment effects, loss of riparian vegetation, degradation of instream habitat, loss of habitat connectivity);
- threat of infrastructure damage (value of infrastructure, importance to owner);
- channel course change (loss of land, damage to infrastructure, isolation of infrastructure, loss of utility); and
- loss of utility (loss of navigability, reduction of recreation values, loss of conservation values).

The magnitude of the consequences to be expected if the problem persists needs to be be determined. This may range from 'minor', where some loss of low value land occurs to 'major', where houses or bridges are threatened or where significant channel change may occur.

Some of the consequences of a problem (for example the degradation of riparian habitat caused by a mass failure) might also be identified as problems in their own right.

Risk

The level of risk associated with a problem and its potential consequences is defined by the magnitude and probability of occurrence. A well defined, predictable and relatively low-cost consequence, such as the gradual loss of land on the outside of a meander bend, would usually be considered a low risk situation, whereas an imminent channel change that threatens high-cost infrastructure would represent a high risk situation.

Associated Problems

In assessing streambank or streambed instability problems, stream managers need to check for other stream management problems. These may be a direct consequence of the instability, may have the same cause as the instability, or may be problems in their own right. Associated problems may be detected during the site investigation or through association with the pressures, as described in Step 2 below. These associated problems may include:

- other instabilities adjacent to the site/reach;
- riparian or instream habitat degradation;
- excessive sedimentation;
- degraded water quality; and
- loss of land or recreation value.

Stakeholder Consultation

Stakeholders can provide useful information on the history, magnitude and consequences of a problem and it is advisable to consult them at this stage.

Comment

The problem that initiates the investigation may have been identified in a number of ways but, most commonly, conventional physical problems (such as streambank instability and loss of land and utility) are identified by adjacent landholders. They may also have been identified as part of comprehensive stream condition surveys that are undertaken by the stream management agency, or as part of reconnaisance surveys undertaken after severe flood events. Other problems, such as habitat and water quality degradation, are not so easily identified and, as they may not be considered significant by the lay person, they may go unrecognised unless specific efforts are made to obtain advice from appropriately-trained specialists.

Take care not to confuse problems with pressures. For example, bank instability and degraded riparian habitat are problems, whereas aggregate extraction and encroachment of agriculture are pressures, which may be the causes of the problems.

In some non-critical cases, where essential data for the development of a stabilisation or rehabilitation program is not available, the stream manager may consider delaying remediation or implementing temporary measures until the required information is available. Identification of such 'holes' in the knowledge-base is a valuable outcome from a project.

How to do STEP 1

Suggested tasks:

1. Collect existing data related to the problem site, the local reach of the stream, other areas of the stream, and the catchment.
2. Collect additional data, such as records of previous works, photographic records of the site and ecological assessments of the region.
3. Consult with stakeholders and funding agencies.
4. Undertake a joint site visit with relevant stakeholders and the multidisciplinary team to see the scope of the problem, to identify obvious issues, to identify obvious additional data requirements etc.
5. Based on catchment information (eg. size, topography, rainfall, biogeography and geological features), and observations of adjoining unaltered reaches, visualise what the site/reach would look like in a natural state. Identifying differences between the actual reach and what it would look like gives a good indication of the problem(s).
6. Evaluate the data and site visit findings.
7. Describe the problem(s).

Much of the information that is sought in Steps 1 and 2 will be obtained from similar sources, and many of the activities will coincide.

The data collection and evaluation activities will proceed in parallel for some time and, therefore, the order of the activities described above is not fixed. It is essential that those who are to identify the problem visit the site, preferably accompanied by stakeholders.

Inputs

The following data will be useful for Step 1 and for some of the subsequent steps:

- photographic records, including aerial photographs of the reach and contiguous land;
- topographic and cadastral maps;
- records of previous ecological, geomorphological, hydrological and engineering studies relevant to the site, the stream and the catchment;
- strategic studies relating to the stream and catchment;
- streamflow records and hydrologic summaries, such as flood frequency analyses, flow duration curves;
- scientific publications relating to the stream and floodplain;
- historical data from newspapers and other publications; and
- anecdotal information from stakeholders and others.

Tools

Table 1.3 lists some of the problems occurring in north-east Queensland streams.

Appendix B provides examples and details of the major groupings of stream management problems.

Personnel

Project Officer, with specialist input from, for example, ecologist, geomorphologist, geotechnical engineer.

Outputs

A complete and accurate description of the problem(s) that initiated the investigation, and of any related problems which became apparent during Step 1.

STEP 2 Identify Relevant Utilities and Pressures

Scope

- **identify the utilities that are affected by the problem; and**
- **identify the direct and indirect pressures that may be contributing to the problem.**

Purpose

To identify the utilities (human uses) that are, or may be, affected by the problem, and to identify the pressures that have contributed to the problem.

It is essential to know the pressures that have contributed to the problem in order to determine the cause of the problem (Step 3). The utilities that will be affected by the problem must be known in order to determine appropriate objectives for remediation (Step 4). The cause(s) of the problem must be accurately determined and the objectives for remediation must be comprehensive if appropriate remediation is to be designed (Step 5 and Step 6).

The process of identifying utilities and pressures may provide additional information that assists in defining the problem.

Human uses

Descriptions and examples of existing and future human uses that may be affected by stream instability and other management problems are presented in Chapter 1. Some affected utilities, such as navigation that is restricted by stream sedimentation, may be readily identified. Effects on other utilities, such as damage to a recreation facility, may not be immediate. Human uses that will be affected by the stabilisation treatment or other management strategies also need to be identified at this stage to ensure that objectives (Step 4) and consequent solutions (Steps 5, 6 and 7) encompass all project requirements.

Pressures

The range of possible pressures on the stream, and their likely consequences, have been introduced in Chapter 1. Detailed descriptions and examples are presented in Appendix A. Pressures need to be comprehensively assessed to ensure that all factors contributing to the problem have been identified.

Table 1.4 provides a relative measure of the likely relationship between human activities (pressures) and stream management problems. For example, (i) slumping mass failures are likely to result from encroachment of agriculture but are unlikely to be instigated by flow regulation; and (ii) indirect pressures from pollution are a likely cause of riparian habitat degradation and water quality problems but are unlikely to cause fluvial bank erosion and slumping failures.

Stakeholder Consultation

Consultation with stakeholders is an important part of this step as it will help in determining community expectations for use of the stream, and in identifying the history, magnitude and results of pressures.

Comment

Table 1.4 can be used to ensure that the full suite of problems and pressures are identified. Firstly, the table provides a simple checklist of the possible problems and pressures, which may help in identifying pressures that are not so obvious. Secondly, the user can confirm previously identified problems and may identify new problems through the relationships with pressures. For example, suppose fluvial erosion problem has been identified. The table suggests that *Channelisation and River Works, Encroachment, Recreation and Boating, and Modified Water and Sediment Regimes from Catchment* are four pressures that are likely to be associated with fluvial erosion. Each of these pressures, especially those that are not obvious from direct observation (eg. *Modified Water and Sediment Regime*), needs to be carefully considered. Other problems associated with these pressures may then be identified (eg. *Degraded Water Quality*).

Take care to differentiate between the role that some facilities play both as utilities and as pressures. Many utilities, such as bridges and recreational fishing, may not present significant pressures; whereas others (such as extraction, water supply and power boating), may represent significant pressures contributing to the problem. Some facilities, for example a road crossing culvert, may have several roles: as a utility (access), as a pressure (accelerated flow), and as a problem (undermining with potential for failure). Identification and differentiation of these roles is important in determining the causes, in defining objectives and in developing appropriate remediation.

How to do STEP 2

Suggested tasks

The tasks scheduled in Step 2 will generally coincide with the activities of Step 1, but will be aimed at determining utilities and pressures rather than at identifying the problem.

Inputs

The same as Step 1

Tools

Tables 1.1 and 1.2 list some of the utilities and pressures relevant to north-east Queensland streams.

Appendix A provides more detailed descriptions of the various pressures that affect streams.

Table 1.4 provides some assistance in identifying pressures.

Personnel

Project Officer, with specialist input in ecology, hydrology, geomorphology and socio-economics as required.

Outputs

A description of the utilities that are, or may be, affected by the problems, and the pressures that have contributed to the problems.

STEP 3 Examine Stream Processes and Determine Causes

Scope

- **identify and describe relevant stream processes; and**
- **determine the most likely cause(s) of stream instability and other problems.**

Purpose

To determine the most likely cause(s) of the problem within the context of the problems that have been described (Step 1) and the pressures that have been identified (Step 2).

An understanding and analysis of stream processes, such as the natural state of, and human-induced changes to, hydrologic flow regime, local hydraulics, geomorphic channel migration, local erosion and sedimentation, and stream habitat, allows the connections between the problems and the pressures to be assessed, and the causes to be determined.

Step 3 provides the basis for subsequent determination of objectives (Step 4) and choice of remediation options (Step 5).

Temporal and Spatial Context

Causes need to be evaluated within the context of the geomorphological processes that are active in the stream system. Whilst the hydrological, hydraulic, erosion, sedimentation, geotechnical and ecological processes will usually need to be considered in some detail, they need to be placed within the context of the broader temporal and spatial scales that define channel and catchment changes.

The temporal context (history) identifies natural variations in stream behaviour and changes in pressures, such as catchment landuse or encroachment on the stream. This helps in identifying and in assessing the expected recurrence of the event(s) that caused the problem. Problems may result from pressures or events that occurred a considerable time ago, and an understanding of these past impacts is necessary to address present problems appropriately.

It may be useful to summarise these data in a timeline format so that the sequence of utility development, changing pressures, observed events, observed problems and the various response to these problems can be readily examined.

The problem must be considered within the spatial context of the reach and catchment, and not solely in terms of the problem at the site. As problems may result from human pressures acting on the stream (direct) or in the catchment (indirect), there is little point in attempting remedial works if the cause of the problem, either on the stream or in the catchment, remains unchecked.

Stakeholder Consultation

Stakeholders, such as landholders and government agencies, will often provide historical flood records and channel change information that will assist in analysing stream processes. Consultation with such stakeholders will usually be undertaken in conjunction with the identification of problems, utilities and pressures in Steps 1 and 2.

Comment

Stream managers need a good knowledge of stream processes for this task. Streambank instability problems and other stream management problems are influenced by a multitude of factors, and a simple decision tree approach to determining the most likely cause(s) of the problem is therefore not appropriate.

It is essential that the cause(s) of the problem are identified in order to determine and implement the appropriate remedial measures. For example, a major rock revetment program might represent a significant waste of resources if the cause of the problem was overbank flow into the stream which could be effectively addressed with minor surface drainage. In another case, standard practices for design of a scour protection structure based on the catchment area of the stream might be inadequate and lead to failure, if the stream manager does not understood that the stream is receiving additional water diverted from an adjacent catchment.

How to do STEP 3

Suggested tasks

1. Obtain required information through data collection and site investigation.
2. Produce a timeline summary of available data, events, problems, remedial works, pressures, utilities.
3. Summarise the effect of the identified pressures on the stream processes.
4. Relate pressures and natural processes to the problems and develop hypotheses of causes.
5. Summarise the causes of the problems.

Examining stream processes within the context of the problems and pressures is an iterative process that terminates when the causes of the problem have been satisfactorily explained. The process involves:

- recognising aspects of the problem that may be caused by specific processes, and/or recognising processes that may be affected by the identified pressures;
- forming a hypothesis of how the processes led to the observed problem;
- obtaining evidence to test the hypothesis through site investigation, data collection, and analysis (eg. hydrological data, geomorphological measurements, geotechnical testing, ecological data, recurrence interval analysis); and
- confirming if this hypothesis is consistent with the collected data and with other observed effects.

Inputs

Data that will be useful for Step 3 include:

- observations from site visits and results from test programs;
- conclusions from Steps 1 and 2;
- photographic records, including aerial photographs of the reach and contiguous land;
- records of previous ecological, geomorphological, hydrological and engineering studies relevant to the site, the stream and the floodplain;
- strategic studies relating to the stream and floodplain;
- streamflow records and hydrologic summaries and analysis such as flood frequency analyses, flow duration curves, ARI of event, flood hydrographs;
- topographic mapping at catchment, section, reach and site scales;
- longitudinal sections of the channel for the reach;
- cross-sections of the channel at the problem site; and
- scientific publications relating to the stream and floodplain.

Tools

Descriptions of stream management problems provided in Appendix B include examples of the likely major causes. Table 1.4 indicates the likely causal relationship between problems and pressures.

Table 1.4 can be a useful *pro-forma* for developing a matrix of pressures, problems, and the causal relationships relevant to the project under consideration.

Personnel

Project Officer, probably with considerable specialist input.

Outputs

Description of the cause(s) of the problem, with particular attention to the active processes that remediation efforts will need to address.

STEP 4 Define Remediation Objectives and Assessment Criteria

Scope

- **define the objectives that remediation treatments need to fulfil if the problem is to be addressed;**
- **define the criteria for assessing the treatment against these objectives; and**
- **define the constraints on the remedial activities.**

Purpose

To specify treatment objectives, the criteria describing the expected performance of the treatment in meeting these objectives, and the legal, physical, environmental, social and economic constraints on the remediation program.

Specifying objectives for the remediation program is an important part of the planning process for a project. Objectives are closely linked to the problems, utilities and pressures identified in Steps 1 and 2. Realistic and achievable objectives are required to enable remediation options to be developed (Step 5), for the options to be evaluated (Step 6), and for a scheme to be selected (Step 7) and implemented (Step 8). The objectives should incorporate monitoring and maintenance requirements (Step 9) such as the nature and frequency of monitoring and the acceptable risk level.

Stakeholder Consultation

Consultation with stakeholders will be required in developing objectives for remediation. Much of this consultation will be undertaken in conjunction with identifying problems, utilities and pressures in Steps 1 and 2.

The appropriate level of consultation must be determined for each case. Broad objectives for addressing particular issues may have already been established where strategic plans for stream or catchment management have been completed. If the remediation program follows these plans, the consultation can deal primarily with local issues relating to the problem.

Scenarios

Stakeholder expectations may well result in a range of physical, ecological and socio-economic objectives for a particular problem. Considering alternative scenarios that emphasise different (perhaps even conflicting) sets of objectives may be the most appropriate way to proceed through to the evaluation stage (Step 6) for complex projects. This ensures that decisions can be made (Step 7) on the basis of the various environmental, social, political and economic values.

Scenarios are usually defined groupings of priority objectives. For example, Scenario 1 may prioritise the protection of infrastructure and place minor importance on rehabilitation of riparian and instream habitats; Scenario 2 may place comparable importance on protecting the infrastructure and on rehabilitating the riparian habitat, but place only minor importance on instream habitat restoration objectives; Scenario 3 may place the highest priority on the objective of restoring fish passage and the least priority on rehabilitation of riparian habitat.

Overriding Objectives

It is recommended that remediation works be undertaken within the guiding principles described in Chapter 1, and incorporate the best practice guides described in Appendix D. Remediation works need to be consistent with any existing long-term objectives for the stream and catchment that may have been developed.

In addition, all remediation works should begin with the following default objectives. Lessening or abandonment of any of these objectives must then be a conscious and justifiable decision, based on the particular circumstances of the project.

1. Maximise preservation of existing natural values and rehabilitation of natural values by:
    - maximising preservation of existing native vegetation;
    - minimising disturbance to natural riparian and instream habitats;
    - removing exotic species where there are no negative stabilisation effects; and
    - preventing and managing new infestation by exotic species.
2. Minimise impacts of construction works on areas adjacent to the site by:
    - providing for minimum disturbance in construction plans and contracts;
    - ensuring contractors understand and agree to obligations for minimum disturbance; and
    - delineating 'no go' limits and enforcing them with contractual penalties.

Legal and Institutional Requirements

Many stream stabilisation and rehabilitation projects will be conducted by organisations that are legally obliged to ensure that remediation programs meet specified objectives in terms of level of control and other aspects. Where these obligations are in place they must be met, but in some situations the appropriateness of these obligations (eg. to provide a 50yr ARI protection level) may be questioned, and more flexible ways need to be sought to allow obligations to be tailored to the situation.

Project objectives must meet institutional requirements such as approval conditions relating to legislation, and permit procedures applying for management agencies.

Constraints

Objectives must be realistic within the legal, physical, environmental, social, political and economic constraints that apply.

- Legal constraints arise from the requirement to satisfy regulations, to fulfil statutory and institutional obligations, or to minimise exposure to liability; they may also arise from land ownership, tenure or use rights.
- Physical constraints result from aspects such as site plan configuration, material types, bank slopes, types of vegetation etc, and can affect factors such as access, slope stability, drainage requirements etc.
- Environmental constraints may affect the types of remediation works that are acceptable - for example, where there is vegetation that should not be disturbed, or where there are limits to the noise, dust and sediment that can be generated; they may affect the ecological remediation that can be achieved - for example, where catchment landuse and infrastructure pressures preclude re-establishment of natural habitats.
- Social constraints may result from landholder needs - for example, if loss of land may render the farming operation uneconomic; or from community expectations - such as the desire to maintain utility of a riparian area for recreation; or the expectation of protection from flooding.
- Political constraints may apply where sections of the community perceive that the proposed remediation is disadvantaging them, or where there is competition for remediation funding.
- Economic constraints may apply to both the economic consequences of the problem in terms of land loss, flood damage etc, and to the resources (finance, equipment, assistance from community groups, assistance from agencies etc.) available for undertaking the remediation works.

Defining the Objectives

Objectives for the project need to define:

- the requirement of the objective (eg. prevent damage to culvert, or re-establish natural abundance and diversity of tree species);
- the level of control required (eg. as per engineering design guidelines, or to prevent damage in events that are more frequent than 5 yr ARI);
- the level of maintenance that it is feasible to provide (eg. annual, seasonal or on demand);
- the level of environmental remediation required (eg. the density of native trees to be planted), if applicable;
- the time frame for remediation; and
- considerations such as decreased liability exposure, minimal negative public opinion etc.

Defining Assessment Criteria

Assessment criteria provide a means of determining the success or failure of a project in meeting the specified objectives. Some assessment criteria will be simple and obvious - for example, if the objective is to complete the remediation program before the next wet season, the assessment criterion will be simply "complete by (date)". For others, the criteria will not be so straightforward, or the success or failure will not be so readily determined. For example, success or failure will be difficult to assess where a bridge abutment is to be protected. The assessment criterion for this might be to "suffer no damage in events below 200 yr ARI". To determine compliance with this criterion, the abutment would require monitoring after all events for indications of damage, and the ARI of all events calculated.

An example of a case where the criteria are more difficult to measure might relate to a habitat restoration objective that specifies "after 5 years, the diversity of vegetation species should be comparable to the adjacent remnant forest". Success or failure of the remediation can be determined at the end of five years, but will require vegetation survey and statistical analysis of the results.

Review of Objectives

In complex projects, objectives may have to be reviewed after the concept design phase (Step 5).

Comment

A high degree of control is appropriate for high risk situations and for the protection of high value infrastructure, whereas lesser control might be an option where minor land loss is the only consequence, or where remote causal pressures are also being addressed. Examples of objectives might be:

- to minimise the likelihood of a problem happening during the engineering lifetime (~50 years), say to protect infrastructure;
- to minimise the likelihood of a problem occurring/worsening on a regular basis (say during the floods that occur virtually every year or two) while allowing it to happen in larger floods, say to provide riparian ecosystems with a more natural disturbance regime;
- to monitor the problem at this time because off-site causal factors (eg. sand extraction) have been reduced; and
- to not instigate control at this time if the landholder can be compensated for a buffer strip.

The level of control and rehabilitation that is required will usually be based on a consideration of:

- ecology, depending on local or regional context of the ecological value of the site;
- geomorphology, depending on the potential to initiate major channel change etc.; and
- socio-economic factors, depending on the value of the infrastructure, value of the land, use of land etc.

Table 3.1 Examples of Objectives

Grouping	**Example Objective**
Physical	▪ Prevent scour at toe of bank, designed to 100yr ARI event. ▪ Provide Factor of Safety = 2, against failure under all conditions. ▪ Prevent outflow scour on top of bank, designed to 100 yr ARI event. ▪ Reduce flow velocities to < 1.0 m/s along overbank outflow path. ▪ Re-align main flow away from eroding bank. ▪ Reduce frequency of occurrence of fluvial erosion of upper bank.
Ecological	▪ Re-instate fish passage through infrastructure. ▪ Re-instate pool/riffle morphology in reach degraded by extraction activities. ▪ Revegetate riparian area with native species, 10 trees per 100 m^2 survive after 1 year. ▪ Repair break in continuity of natural riparian habitat, vegetation species diversity to be 80% of existing adjacent areas within 5 years. ▪ Remove exotic plant species from riparian area. ▪ Improve water quality to drinking water standards.
Socio-economic	▪ Protect bridge abutments from scour, designed to 200yr ARI event. ▪ Minimise rate of loss of arable riparian land. ▪ Maintain navigability of stream for 1m draft vessels. ▪ Create buffer strip adjacent to stream and compensate landholder. ▪ Improve recreation and aesthetic values of riparian land.

How to do STEP 4

Suggested tasks

1. Review strategic plans and policies.
2. Review legal requirements.
3. Undertake appropriate consultation and summarise stakeholder objectives.
4. Identify any additional objectives based on analysis of the problem, the utilities and pressures, and the causes.
5. Define assessment criteria.
6. Summarise constraints.
7. Put sets of objectives into scenarios as appropriate.
8. Outline the following data for objectives within each scenario:
    - requirement of the objective;
    - level of control required (if appropriate);
    - level of maintenance that is acceptable;
    - level of environmental remediation required;
    - time frame for implementation;
    - resources available;
    - priority for this objective within the scenario; and
    - criteria by which degree of success in achieving objective can be judged.

Inputs

Outputs from Steps 1-3.

Strategic plans, planning policy statements.

Consultation results.

Tools

Some examples of objectives are presented in Table 3.1.

Personnel

Project Officer, with specialist input as required.

Outputs

Definitions of objectives grouped into scenarios.

Constraints on project.

STEP 5 Identify Remediation Options and Develop Concept Designs

Scope

- **identify a short list of remediation options that may contribute to meeting the specified objectives;**
- **group appropriate options into schemes; and**
- **develop concept designs of alternative schemes.**

Purpose

To identify remediation options that can assist in meeting the project objectives; to group these options into schemes that are targeted to meet the requirements of different scenarios; to develop concept designs for each of these schemes. This is the final step in the concept phase.

A concept design will be required for each scheme, and several schemes may be suggested for each scenario. For example, two schemes assigning comparable priority to the protection of infrastructure and rehabilitation of riparian habitat may be suggested for a particular scenario. These schemes may have some common components, such as methods of habitat restoration, but may use alternative stabilisation treatments such as rock groynes and rock revetment.

Remediation Options

Potential stream management strategies and stream stabilisation and rehabilitation treatments are identified in Chapter 1 and detailed descriptions and characteristics of stabilisation treatments are presented in Appendix C.

Table 1.5 provides a relative measure of the likely suitability of individual strategies and treatments in meeting stream management objectives. This table can be used as an initial guide to options that might be useful, but these options need to be evaluated in the context of particular circumstances of each case. It is possible that a treatment, rated in Table 1.5 as likely to be appropriate, may be inappropriate for the particular circumstances. For example, Table 1.5 illustrates the following:

- All treatments may be useful in treating streambank erosion (indicated by a rating of at least 3), except for *Clearing and Desnagging* which is unlikely to be useful (indicated by a rating 2).
- Apart from the grade control treatments *Bed Chute* and *Drop Structure*, and catchment and stream restoration approaches, most other treatments are unlikely to be appropriate for control of bed erosion.
- Native vegetation is likely to contribute to meeting most objectives, and is excellent for improving environmental quality.

When considering strategies and treatments to meet the objectives for a particular project, it may be useful to produce a table similar to Table 1.5 but including only objectives relevant to that project, and accounting for the specifics of the project when assessing the likelihood of success of a treatment. The rating table so produced for the project can then be used to assess strategies and treatments that can be combined into potential schemes.

Combinations of strategies and treatments will often be required to meet desired objectives for a site (eg. rock revetment and vegetation may be used in conjunction with a pile groyne structure).

Vegetation is a useful component of all remediation designs.

In some designs, the vegetation treatment may make a major contribution to stabilisation, as well as to habitat restoration. For others, for example where objectives call for hard engineering treatments, vegetation will be necessary to re-establish riparian habitat.

It is often desirable that remediation schemes provide for reclamation of a strip of land along the top of the bank and re-establishment of an 'esplanade' of riparian vegetation where this land has been cleared or severely degraded.

The non-intervention option should always be considered, although in many cases it will not be appropriate.

Concept Design

Concept designs should convey the intent of the designer in meeting the project objectives and should define the scope and nature of the alternative schemes. The level of detail will vary between projects but concept designs will normally include:

- which treatments are to be combined;
- how the remediation is intended to work;
- layout plan of the scheme showing approximate extent of treatments;
- example elevations and sections illustrating features of the design;
- estimated sizes and extent of various treatments (length and height of groynes, areas of revegetation, areas of rock etc.); and
- degree of control that will result from alternatives.

The conceptual design needs to consider the following factors, although at this stage a detailed analysis would usually not be appropriate:

- construction methods and required machinery;
- access to site and operating space for machinery;
- storage of construction materials;
- disturbance during construction; and
- potential deleterious impacts of remediation treatments.

It is unlikely that remediation schemes will fully meet all objectives of a scenario. Designs and objectives may need to be re-assessed.

Stakeholder Consultation

It may be useful to arrange for consultation with stakeholders to obtain feedback about the concept design before proceeding to feasibility design and evaluation, especially in projects where objectives have been significantly influenced by stakeholder input.

Comment

The process of identifying suitable treatment options and developing conceptual designs to satisfy best the project objectives has a large intuitive component that draws heavily on experience. These guidelines do not replace this intuition and experience, but aim to ensure that all relevant physical, ecological and socio-economic factors are considered in the development of remediation programs.

Engineering design of the physical aspects of treatments is directed towards achieving a specified degree of control of a problem by the use of factors of safety, recurrence intervals of flood events etc. For 'softer' solutions (that incorporate vegetation for example), the certainty of achieving a specified degree of control is reduced. This does not necessarily mean that the control of a problem will not be provided, but it means that there is no accepted way of quantifying the control or proving how a particular design will behave.

How to do STEP 5

Suggested tasks

1. Determine appropriate basic strategies and select potentially suitable treatments using Appendix C and Table 1.5 as guides.
2. Consider combinations of treatments into schemes that satisfy objectives for each scenario.
3. Develop concept designs which tailor combinations of treatments to the site.
4. Document concept design using drawings, sketches, notes etc. as appropriate.
5. Seek stakeholder input on concept designs if appropriate.

Inputs

Knowledge of site from Steps 1 and 2.

Understanding of stream processes, problems and their causes from Step 3.

Objectives for remediation from Step 4.

Tools

Table 1.5 suggests the likely suitability of remediation treatments in meeting stream management objectives.

Appendix C provides detailed descriptions of stream stabilisation treatments, including their useful application, their limitations, design and construction considerations, and their physical, ecological and socio-economic characteristics.

Personnel

Project Officer. Specialist input obtained as required.

Outputs

Conceptual designs of schemes that address each scenario of objectives. One or more schemes may be established for each scenario.

STEP 6 Feasibility Design and Evaluation

Scope

- **prepare feasibility designs for the schemes identified for each scenario in the concept design stage (Step 5); and**
- **evaluate schemes against the physical, ecological and socio-economic objectives and assessment criteria established in Step 4.**

Purpose

To advance the alternative schemes produced in Step 5 to a feasibility level design, and then to assess the designs against project objectives (established in Step 4) to form the basis for decision making in Step 7.

Full feasibility design may not be required for all schemes developed in the concept design phase. Some schemes may be eliminated early in the evaluation process.

For some remediation schemes (eg. non-intervention, revegetation) only minimal, or even no, design may be required. In such cases, the feasibility design and evaluation will require little effort, and may effectively be skipped.

Review

In many projects the feasibility design step represents a significant cost, so a review of issues may be appropriate before embarking on the designs. The present understanding of the problems, pressures, utilities and stream processes needs to be reviewed in light of any additional information that may have been obtained in Steps 4 and 5. Project objectives should similarly be reviewed and confirmed, possibly leading to a review of the concept designs.

Feasibility Design

Feasibility design takes the concept designs of Step 5 to a level where their effectiveness and cost can be assessed and comparisons made between alternatives. Feasibility designs will normally present:

- treatments and materials;
- how the treatments will be combined into an overall remediation program (eg. bank profiling, drainage, rock, revegetation);
- expected construction methods;
- access and site space requirements;
- near-final layouts of treatments, locations relative to reference points, profiles of banks etc.;
- near-final configuration of revegetation activities;
- details of construction site rehabilitation;
- near-final estimates of sizes of components (eg. piles, rocks, gabions);
- near-final quantities (eg. rock, soil, earthmoving, vegetation); and;
- near-final costs.

Feasibility designs will often require significant additional site assessments, such as geotechnical investigations, and further assessment of stream processes, such as flood hydrology, hydraulics and sediment transport. Whereas previous site assessments were focused on finding the cause of the problem, at this stage they are focused on the requirements of designing the remediation solution.

Remote and local effects need to be considered as an integral part of the feasibility design analyses and evaluations. This would include the geomorphic consequences of the design (eg. channel change), possible remote ecological consequences (eg. downstream dispersal of seed), and implications for flooding.

The feasibility design stage may consider several alternative schemes for each scenario of objectives. These alternatives would typically employ different strategies, different types of treatments, or alternative types of the same treatment.

Evaluation of Alternatives

The feasibility design phase has an inherent evaluation component where options are assessed and judgements made on their suitability. This is an iterative process of increasing design detail and re-evaluation of alternatives leading to a final feasibility design for each scheme. Completed feasibility designs should be evaluated in the broader stream context to ensure that there are no unintended geomorphic consequences or unintended effects on recreation, aesthetics or cultural values.

Some decisions may be related to economic, social (and even political) matters rather than technical considerations. A comprehensive evaluation of options, which includes all relevant issues, including social and political ones, is advisable.

Evaluations would normally incorporate:

for each option-

- consequences of undertaking this option;
- summary of benefits (related to project objectives);
- summary of costs; and
- summary report on the degree to which objectives are satisfied.

overall-

- precis appraisal of each option;
- summary of methods of comparative analysis that were used; and
- summary of comparison between options.

Methods of project evaluation are briefly discussed earlier in this Chapter.

In many projects, particularly complex ones involving a number of scenarios, the decision on which scheme is to be adopted may not be made by the project team, but by others such as the client or project steering committee. The feasibility design and evaluation should provide the basis for a final choice of the remediation program to be made in Step 7. This ensures that the technical evaluation step does not introduce any unintended value judgements on the importance of individual objectives that may influence the decision.

The evaluation should present options and a recommended scheme for each feasible scenario that is taken through to Step 7 for a decision. For simple projects, only one scheme may be feasible and no other options are presented for decision.

How to do STEP 6

Suggested tasks

1. Review problems, pressures, utilities and stream processes.
2. Review and confirm objectives.
3. Review concept designs.
4. Confirm choice of options to be considered in alternative schemes.
5. Determine design data requirements and undertake relevant field investigations.
6. Determine appropriate design cases and design parameters.
7. Undertake appropriate analyses and design studies and develop feasibility designs of viable options.
8. Evaluate viable options to provide data requirements of comparative study.
9. Produce comparative evaluation of alternative designs.
10. Recommend scheme that best meets the priority objectives within each scenario.

Inputs

Shortlist of suitable treatments and alternative concept designs from Step 5.

Project objectives from Step 4.

Site assessment and stream process data.

Tools

Information on stream stabilisation treatments (Appendix C).

Guiding principles presented in Chapter 1.

Best practice guides (Appendix D).

Structured evaluation techniques introduced in Section 3.2.

Personnel

Project Officer. Specialist input as required. Probably a major role for an engineer if alternative designs include structural works. Specialist input may be required in the evaluation phase.

Outputs

Documentation of alternative feasibility design for each scenario.

Evaluation report on recommended scheme within each scenario.

STEP 7 Decide on Remediation Program

Scope

- **decide on the remediation scheme that is to proceed to detailed design and implementation.**

Purpose

To choose the remediation alternative to be implemented. By this stage, strategies and treatments will have been combined and integrated into concept designs of remediation schemes that address the priority objectives of each scenario (Step 5). These schemes will have been tailored to the site, will have been developed to a feasibility design level (Step 6), and will have been evaluated to provide the basis of the information required to decide between alternatives.

This would normally be the final step in the feasibility phase.

Decision

The final decision between alternatives will often be made by people other than those preparing the technical designs and analyses. For example, the decision might be made by a steering committee, stream management agency, or local authority, or an advisory group might make the final decision and pass recommendations to the proponent of the project.

Each decision will be unique in the factors that must be considered in the final choice. Matters of risk, economics, availability of funding, public perception and policy are often important in the decision step.

In simple projects the decision will be made earlier in the process and no detailed consideration of alternatives will be required at this stage.

How to do STEP 7

Suggested tasks

1. Consider appropriate scenarios.
2. Consider recommended scheme within each scenario.
3. Make decision.

Inputs

Evaluation reports of alternative feasibility designs.

Policy, economic and other matters.

Personnel

Usually decided by the client, stream management agency or steering committee, rather than by the Project Team.

Outputs

Decision on which remediation alternative will progress to detailed design and implementation.

STEP 8 Detailed Design and Implementation

Scope

- **finalise the layout, configuration and size of the components of the adopted scheme;**
- **finalise selection of materials, species, construction methods etc.;**
- **prepare tender documentation;**
- **award tenders; and**
- **manage construction or implementation of the scheme.**

Purpose

To complete the detailed design of the chosen remediation program, and manage the implementation of the program.

Revegetation programs will usually require limited design detailing in comparison with structural works. For non-intervention options, implementation requirements will usually be limited to stakeholder consultation.

Drawings, specifications and instructions for the required work need to be prepared to a standard that enables tenders to be called.

Detailed Design

This process entails finalisation of all details that are required to enable the project specification and tender documents to be prepared. This will usually involve:

- layout and configuration of scheme components;
- detailed engineering design of structural components;
- choice and specification of construction methods (if appropriate);
- other layout details (eg. drainage, revegetation, no-go areas);
- selection of species for revegetation; and
- design of maintenance programs (if appropriate).

The detailed design phase may require further site assessment. This will usually be related to specific components of the adopted scheme and the requirements will usually be very well defined.

Detailed designs best incorporate the best practice guides of Appendix D.

Specification

The project must be specified adequately to allow tenders to be obtained and evaluated, and implementation to be completed with a minimum of variations. For stream stabilisation and rehabilitation projects, documentation needs to provide an integrated specification of the physical and ecological requirements of the project. The best practice guides (Appendix D) are useful for developing specifications. Particular care needs to be taken in specifying:

- requirements for minimal disturbance;
- requirements for preservation or rehabilitation of topographic features, such as pools and riffles;
- relevant performance criteria for all requirements, and penalties for non-compliance;
- materials to be used;
- construction methods to be used;
- revegetation requirements, including areas to be planted, preparation requirements, planting and establishment methods, maintenance requirements; and
- monitoring and documentation requirements.

Contract Documentation

Contract documentation will in many cases follow the standard format of the funding organisation but, for stream stabilisation and rehabilitation projects, particular attention also needs to be paid to:

- responsibility for access to the site;
- responsibility for obtaining required permits for construction;
- specifying a mechanism to handle variations that arise from review of construction performance;
- responsibilities of contractors' staff, sub-contractors etc. in ensuring minimal disturbance;
- construction site management requirements; and
- maintenance responsibilities.

Construction

Construction practice needs to include:

- pre-construction conference to ensure contractors' responsibilities to environmental care, as well as the more traditional responsibilities, are understood;
- best efforts to minimise disturbance due to storage, access, facilities, and construction activities;
- clean-up and rehabilitation of construction impacts on completion;
- scheduling to avoid wet season construction; and
- adoption and implementation of the best practice guides of Appendix D.

Construction Management

Management of construction is required to ensure that the intent of the design is realised. Field training and education, to ensure all personnel understand the environmental objectives of the project and their responsibilities, will reduce supervision requirements and minimise penalties and post-construction rehabilitation requirements.

How to do STEP 8

Suggested tasks

1. Obtain remaining site data required to finalise detailed design.
2. Make final decision on the materials, species, etc.
3. Complete detailed design and produce drawings and specifications.
4. Produce tender documents and call for tenders.
5. Evaluate and award tenders.
6. Award contract for remedial works.
7. Manage construction and implementation of remediation program.

Inputs

Feasibility design of chosen option.

Site assessment data from previous steps.

Tools

Information on Stream Stabilisation Treatments (Appendix C).

Best practice guides (Appendix D).

Traditional engineering design tools.

Personnel

Final design, specification and documentation will usually be organised by the Project Officer.

Implementation of remedial works may be undertaken by a stream management agency (eg. river trust or local authority), or by contract.

Project is usually managed by the design consultant or Project Officer, perhaps requiring specialist assistance at times (eg. engineering supervision during construction, horticultural supervision during revegetation etc.).

Outputs

Completed remediation works.

Documentation of completed remediation program as per contract (eg. photographs, as-constructed drawings etc.).

STEP 9 Monitoring and Maintenance

Scope

- **monitor the performance of the remediation works; and**
- **maintain the remediation works.**

Purpose

To monitor the performance of the remediation works to determine if modifications are necessary and if lessons for future remediation programs can be gained. To monitor the condition of the works to identify maintenance requirements, and to maintain the remediation works as required for establishment of vegetation and repair of damage.

Monitoring and Evaluation

Regular inspection and monitoring is required to allow evaluation of the works against the performance criteria established in Step 4. These evaluations may prompt modifications to the works if they are not performing satisfactorily, and will contribute to the knowledge of remediation techniques and to the advancement of stream stabilisation and rehabilitation.

The monitoring and evaluation program needs the following features:

- a pre-construction baseline survey and report on pre-construction conditions;
- regular (eg. annual) inspections, plus inspections during (if possible) and after critical events;
- a consistent set of observations using a consistent and repeatable methodology (eg. photographs and observations from known points, topographic survey on known transects, ecological sampling using consistent methods and intensity);
- a reporting and recording program that ensures monitoring and evaluation data are available for present and future use;
- a mechanism for initiating maintenance if required; and
- a mechanism for periodic feedback to stream stabilisation and rehabilitation practitioners.

Short-term monitoring may be important for feedback on construction performance and vegetation establishment, but monitoring over the first two years and after the first major flood event will be critical for assessment performance of the remedial treatments. Evaluation after five or ten years or so may be necessary to determine project success (Step 10).

Maintenance

Maintenance may be required to:

- ensure vegetation becomes established; and
- repair any damage which occurs to the treatment(s).

Where damage occurs, a thorough investigation of the causes of the damage needs to be made, modifications to the remediation works made as required, and modifications to the design noted for future remediation programs.

Before proceeding to repair damage, the stream manager will need to confirm that maintenance is necessary, as it is possible that some apparent damage does not affect the performance or durability of the treatment. Where a remediation program consistently requires repair, the causes of the damage should be carefully analysed, and the merits of establishing a different remediation program should be considered.

A regular program of monitoring and inspection will enable early detection of problems, which will reduce maintenance costs and avoid extensive problems.

Stakeholder Consultation

Consultation with stakeholders, particularly landholders and government agencies, will usually be beneficial in determining performance of the treatment and in assessing maintenance requirements.

Comment

Vegetation should be watered, weeded, fertilised and otherwise maintained until plants are sufficiently established to survive independently. Different components of the maintenance program may need to be continued for different periods. For example, the planted area may need to be watered for only a few months, while weeding may be required periodically until a canopy is established.

How to do STEP 9

Suggested tasks

1. Maintain newly established vegetation.
2. Establish elements of monitoring program.
3. Establish schedule of monitoring inspections.
4. Establish schedule of monitoring reports and elements of reports.
5. Conduct monitoring inspections and report.
6. Advise of repair requirements.
7. Repair damage as required.
8. Transfer to other practitioners the knowledge gained from monitoring.

Inputs

Performance assessment criteria from Step 4.

Tools

Monitoring program *pro formas* and maintenance manuals, as applicable.

Personnel

Project Officer. The proponent of the project (eg. local authority of river improvement trust) will most likely oversee the monitoring program once the implementation phase is completed. Specialist input will usually be required.

Outputs

Monitoring history of project.

Maintained remediation works.

Documentation of lessons learnt from the project.

STEP 10 Review

Scope

- **review the project, report on performance, and suggest improved practices.**

Purpose

To review the project formally and report on how well project objectives have been met, and what improved practices the experience of the current project has suggested.

Review

The review of the project should provide:

- the history of the project;
- an assessment of how well the project met the objectives;
- a record of how practices changed during the project as a result of monitoring the performance of the works, and of other project experiences (including photographs); and
- recommendations for improving similar projects in the future.

Projects should be reviewed more than once. An initial review on completion can deal primarily with planning and implementation aspects, and a second review after two years can report on establishment of vegetation. Subsequent reviews should be undertaken whenever something notable occurs (eg. damage from a flood), and a final review undertaken after five to ten years. Even after this final review, the performance of the remediation works should still be monitored and significant events should be reviewed and reported.

Technology Transfer

It is useful to disseminate the results of project reviews to stream management practitioners through conferences, workshops and other fora to ensure that successful practices, and improvements to present practice, become widely known.

How to do STEP 10

Suggested tasks

1. Review performance of project with regard to objectives.
2. Assess and report on how well project has met each of the objectives.
3. Report on improved practices identified during project.
4. Recommend improvements to planning and implementation process, design of treatments, implementation methods, monitoring and maintenance practices.

Inputs

Objectives of design chosen in Step 7.
Data from monitoring.

Personnel

Immediate post-construction review organised by Project Officer. Responsibility for continuing the review process will then have to be taken over by the project proponent (eg. local authority, or river improvement trust).

Specialist input to the reviews may be needed.

Outputs

Performance review.
Recommendation for improved practices.

3.4 Recommended Reading

Brookes, A. and Shields, F.D. 1996, *River Channel Restoration Guiding Principles for Sustainable Projects*, John Wiley & Sons, Chichester.

Construction Industry Research and Information Association 1990, *Use of Vegetation in Civil Engineering*, University Press, Cambridge, 292p.

Department of Conservation and Environment 1990, *Environmental Guidelines for River Management Works*, prepared for the Standing Committee on Rivers and Catchments, Melbourne, 58p.

Gardiner, J.L. 1991, *River Projects and Conservation, A Manual for Holistic Appraisal*, John Wiley & Sons, Chichester, 231p.

Gray, D.H. 1976, 'Role of woody vegetation in reinforcing soils and stabilising slopes', in *Proceedings of the Symposium on Soil Reinforcing and Stabilising Techniques*, Sydney, pp. 253-306.

Hemphill, R.W. and Bramley, M.E. 1989, *Protection of River and Canal Banks, A Guide to Selection and Design*, water engineering report for the Construction Industry Research and Information Association, Butterworths, London, 200p.

ID & A Pty Ltd 1996c, *Natural Channel Design Guidelines*, manual prepared for Brisbane City Council.

Melbourne Water 1993, *Environmental Evaluation Handbook*, Melbourne.

Newbury, R.W. and Gaboury, M.N. 1993b, *Stream Analysis and Fish Habitat Design, A Field Manual*, Newbury Hydraulics Ltd, Gibsons, British Columbia.

Raine, A.W. and Gardiner, J.N. 1995, *Rivercare Guidelines for Ecologically Sustainable Management of Rivers and Riparian Vegetation, Occasional Paper No 03/95*, prepared for Land and Water Resources Research & Development Corporation.

Read Sturgess and Associates, and Ian Drummond and Associates Pty Ltd 1992, *Rapid Appraisal of the Economic Benefits of River Management*, prepared for the Department of Water Resources, Victoria, 189p.

Rutherfurd, I.D., Marsh, N, Jerie, C. and Bunn, S.E. (in preparation), *A Guide to the Physical Rehabilitation of Australian Streams*, published by the CRC for Catchment Hydrology, and LWWRDC, Canberra.

Sinden, J.A 1988, *Valuation of Unpriced Benefits and Costs of River Management, A Review of the Literature, A Case Study of the Recreation Benefits in the Ovens and King Basin*, report prepared for the Department of Water Resources, Victoria, 96p.

Standing Committee on Rivers and Catchments 1991, *Guidelines for Stabilising Waterways*, prepared by the Working Group on Waterway Management, Melbourne.

Chapter 4 - Case Studies

The following case studies illustrate applications of the approach and techniques presented in this document.

The work being undertaken at each site is ongoing. Monitoring and analysis of each site is continuing and the full effects of the treatments being implemented are yet to be seen.

Further information about the efficacy of the treatments at each site can be obtained from the authors and from the project owners.

- Case Study 1 - Mulgrave River Stewart Road
- Case Study 2 - Herbert River Anabranch Bube
- Case Study 3 - Haughton River Mill Farm
- Case Study 4 - O'Connell River Study Site

Case Study 1
Mulgrave River Stewart Road

Stream

The Mulgrave River enters the Coral Sea a little downstream of its confluence with the Russell River at Mutchero Inlet. The Stewart Road site is located on the Mulgrave River approximately 10 kilometres upstream from its mouth, and approximately 18 kilometres south east of Gordonvale (Figure 1).

Mulgrave-Russell Rivers Basin Hydrology

Area: 2 020km²

Mean Annual Rainfall: 3 233mm

Mean Annual Runoff Volume: 4 193GL

Maximum Instantaneous Discharge (Mulgrave River, Feb 1977): 3 354m³/s

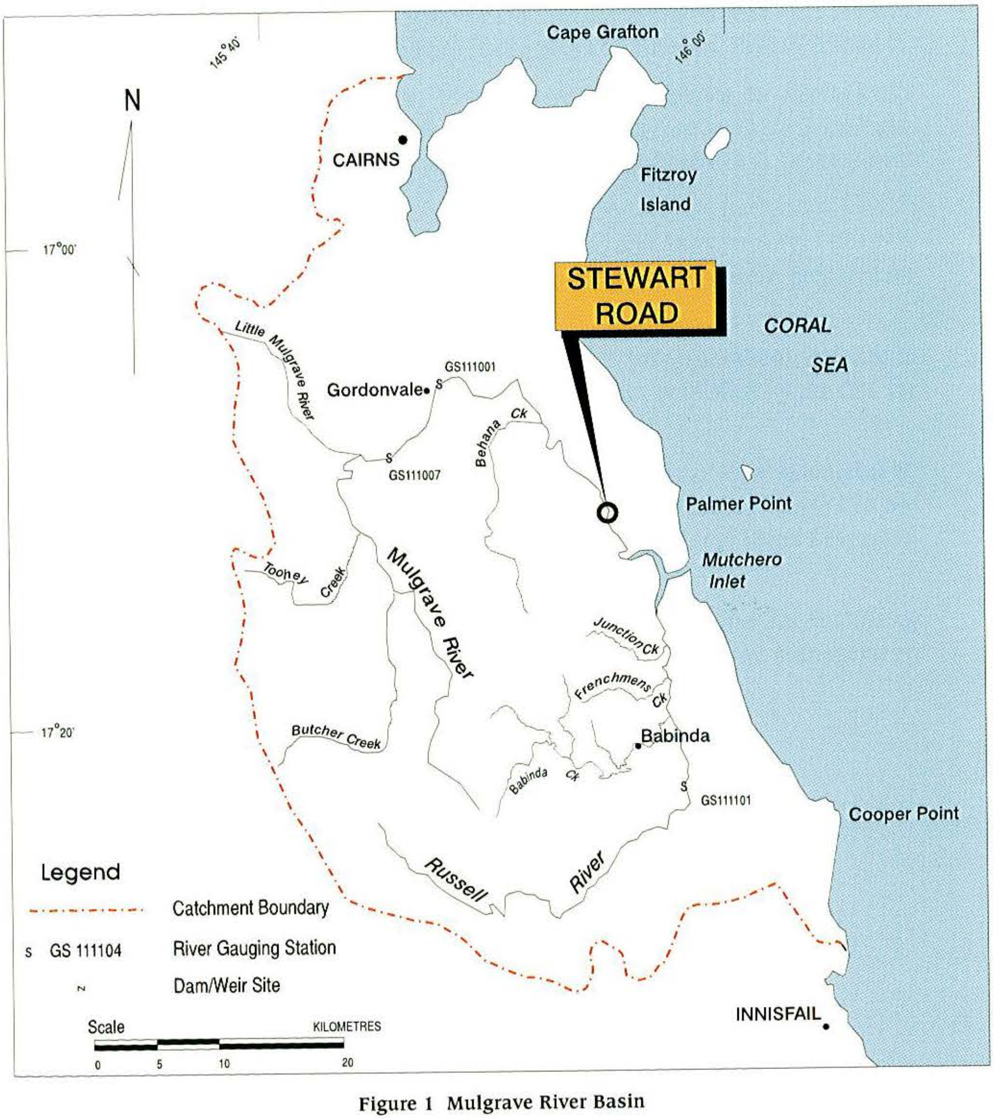

Figure 1 Mulgrave River Basin

Environment

The site is located in the wet tropics and experiences high rainfalls during the characteristic warm humid summers. The Mulgrave River floodplain lies in a narrow valley confined by coastal ranges. Coastal lowland tropical forests that previously covered the floodplain are now poorly represented due to clearing. Sugarcane cultivation is the predominant landuse. Streambed deposits are principally sandy, and stream banks comprise loamy cohesive soils. The river is tidally influenced in its lower reaches, although the water at the site is seldom saline due to the perennial freshwater stream flow.

Case Study Site

The Stewart Road site lies on the outside of a meander bend, bordered by sugarcane and a remnant section of tropical lowland forest that has significant conservation value (Plates 1 and 2). The stream banks are susceptible to fluvial erosion (undercutting) as the predominant soils are cohesive silty and clayey sand topsoils overlying layers of silty clays and loose sands. Streambank erosion has caused some loss of sugarcane land and has threatened the integrity of the forest (Plate 3). The erosion has also threatened to outflank bank stabilisation works that had been constructed at the upstream end of the site in previous attempts to halt the erosion.

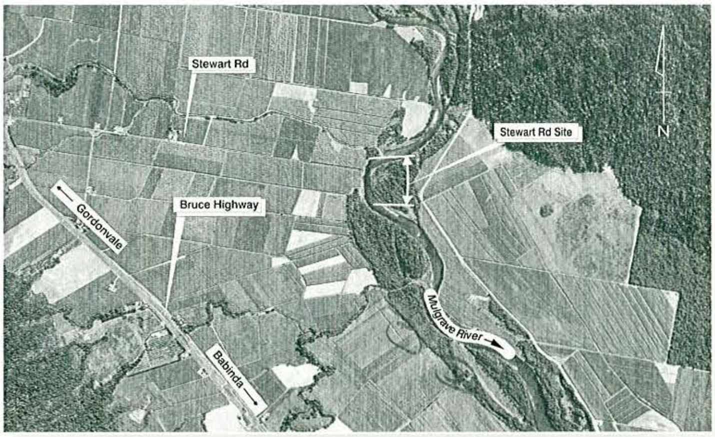

Plate 1 Mulgrave River Stewart Road Locality Plan
Source: Sunmap aerial photo, Bartle Frere 1992, Run 6, No. 067

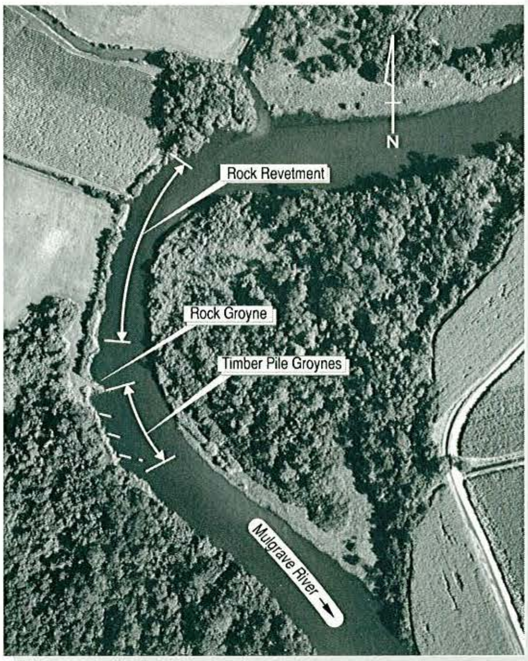

Plate 2 Stewart Road Reach Plan
Source: NorthAir survey aerial photo, Mulgrave River 1996, Run 1, No.120

Plate 3 Eroded stream bank prior to construction of pile groynes; showing remnant riparian forest

A section of rock revetment several hundred metres long was constructed immediately upstream of the site in the 1980s. A rock groyne was subsequently constructed downstream of the rock revetment, and the top of the river bank adjoining the rock revetment was revegetated with native forest plantings during 1993. A timber pile groyne alignment training structure was constructed in 1995 at the downstream end of the site adjoining the remnant forest. The objective of this work was to preserve the forest, maintain the existing stream alignment, stabilise downstream sedimentation, and protect the existing stabilisation works.

Strategies & Treatments

Three rows of pile groynes were installed, angled downstream to the bank, with a tapered top profile that sloped away from the bank (Figures 2 and 3, Plate 4). In order to minimise disturbance to the riparian vegetation, the groynes were constructed from a barge in the water. Rock protection to the bank at the end of each groyne was placed from the bank.

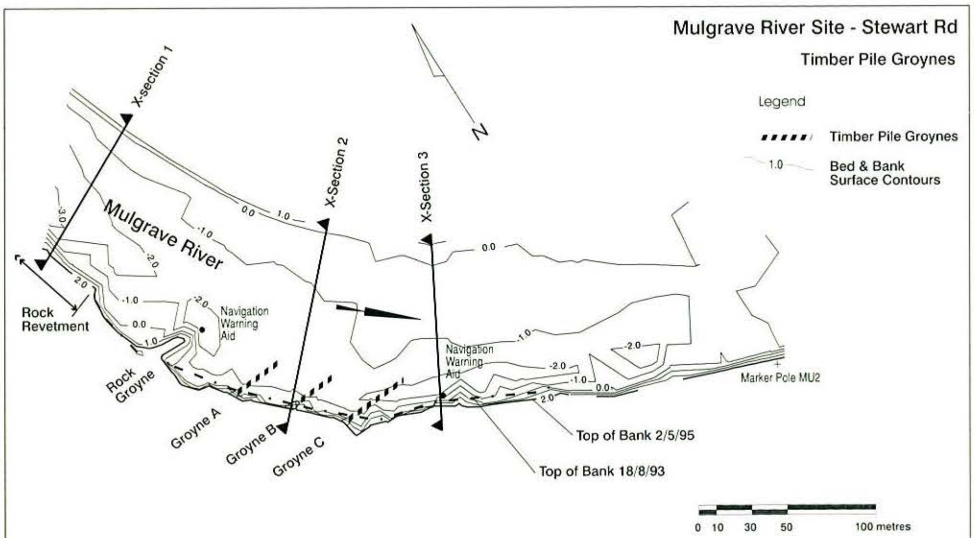

Figure 2 Site Plan

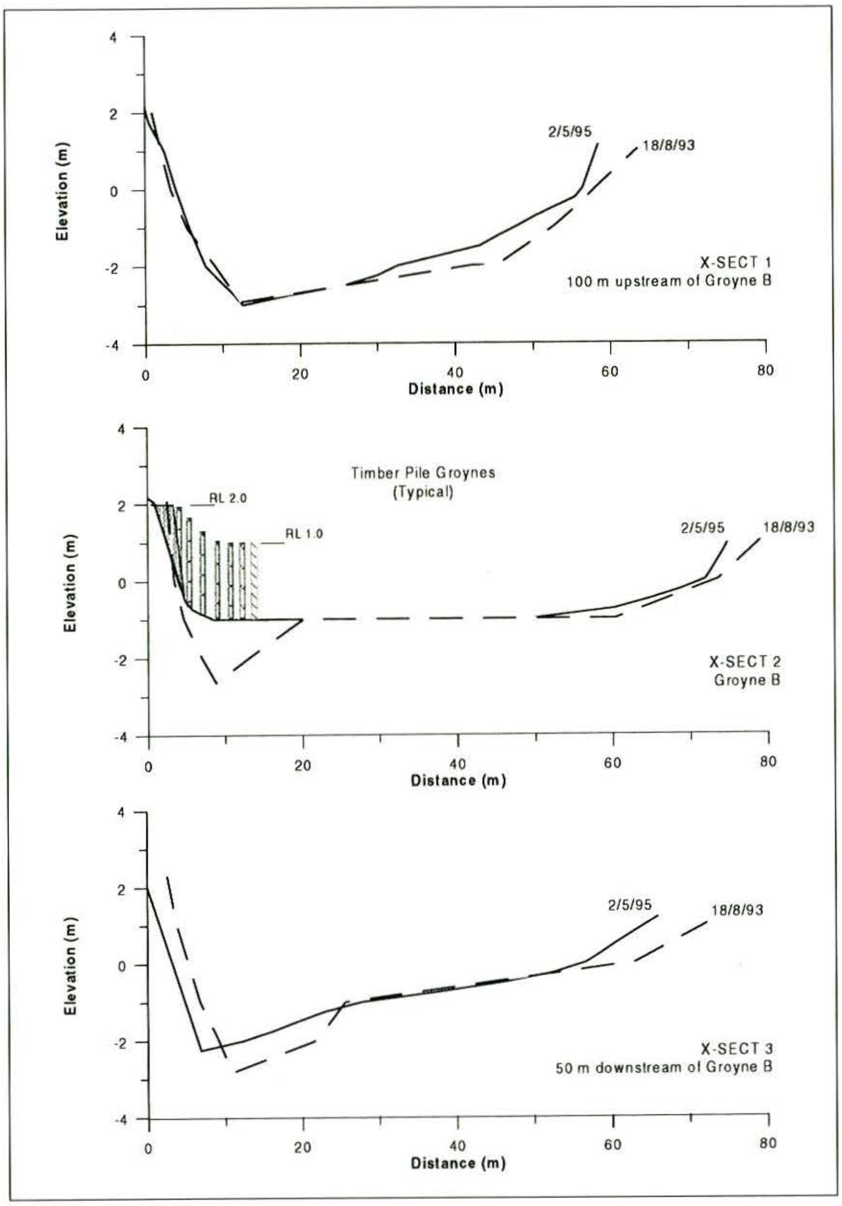

Figure 3 Treatment Cross-sections

Plate 4 Pile groynes

Monitoring & Performance

The pile groyne project has been developed as a trial, to examine the feasibility of stabilisation works other than rock revetment and rock groynes in a sensitive environmental location. The physical monitoring program consisted of pre- and post-construction topographic survey and aerial photography. Biological monitoring of the site encompassing the groyne and the existing rock revetment site was undertaken prior to construction.

Minor flood events in January - February 1994 and February - March 1995 caused some bank erosion at the site. This bank migration occurred prior to installation of the pile groynes (in April - May 1995). Flows in 1995/96, after construction, were not substantial enough to cause any measurable change in the streambed or banks or to provide data on the performance of the groynes. A more substantial flood occurred in March 1997, resulting in no apparent damage. The aerial photo series that spanned the construction period shows some degradation of the vegetation on the edge of the stream bank, apparently due to construction access.

Summary

This project is an interesting pilot study into the suitability of timber pile groynes for alignment training in tropical streams. These stabilisation works are more ecologically suited to the site than rock revetment as they retain the natural riparian land/water interface in the rainforest. The timber groynes are also aesthetically pleasing. The construction method employed for driving the piles (from a barge in the water) appears to have satisfactorily protected the riparian forest, but the clearing and trafficking undertaken for placement of the rock revetment at the end of the pile groynes appears to have allowed the introduction of exotic plants and degraded the vital strip of riparian habitat on the very edge of the stream. The ability of this type of structure to correct the erosion pattern resulting from the upstream riparian clearing and construction of stabilisation works, is of ongoing interest.

Contributing Organisations

Owner	Mulgrave Shire (Cairns) River Improvement Trust
Design	Department of Primary Industries (Department of Natural Resources) Connell Wagner
Construction (Year)	McGarry Enterprises Pty Ltd (1995)
Monitoring	James Cook University Mulgrave Shire (Cairns) River Improvement Trust

References

Connell Wagner 1994, *Mulgrave River Erosion Protection Groynes, Tender Document Contract No 175100CW,* prepared for Mulgrave Shire River Improvement Trust.

Kapitzke, I.R. and Sands, L.B. 1996, *Site Monitoring Report - Physical Component, Research Report No 5,* prepared by James Cook University for the Land and Water Resources Research and Development Corporation.

Case Study 2
Herbert River Anabranch Bube

Stream

The Herbert River Anabranch is a distributary flood channel of the Herbert River, flowing into the Hinchinbrook Channel via the Seymour River (Figure 1). The case study site is situated on the Anabranch, approximately 15 kilometres north-east of Ingham.

Herbert River Basin Hydrology

Area: 10 130km^2

Mean Annual Rainfall: 1 331mm

Mean Annual Runoff Volume: 4 991GL

Maximum Instantaneous Discharge (Mar 1967): 11 919m^3/s

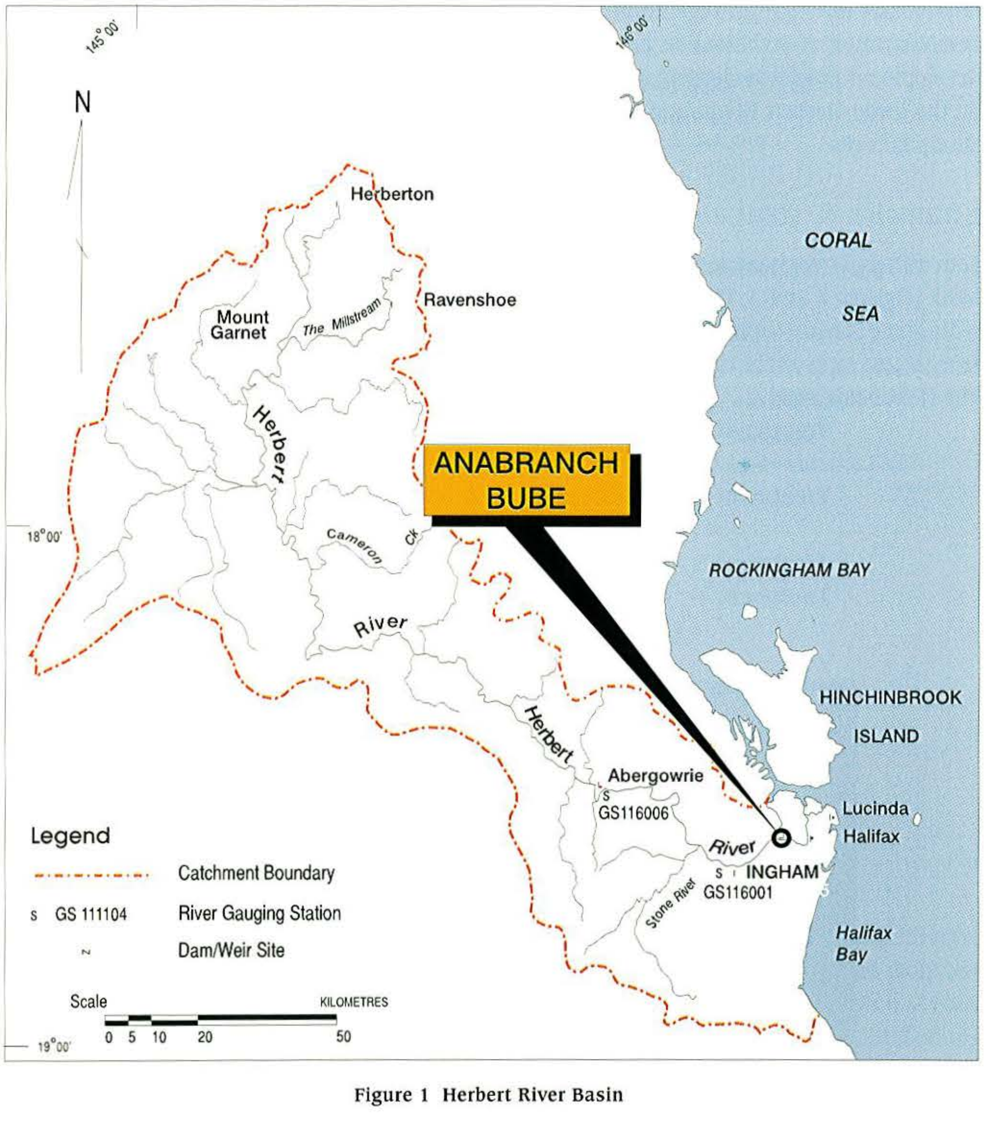

Figure 1 Herbert River Basin

Environment

The site is located in the wet tropics, which is characterised by warm humid summers and mild dry winters. The alluvial floodplain deposits of the Herbert River are very fertile, with a natural vegetation of tropical forest. Much of the native vegetation has been cleared for the cultivation of sugarcane, which is now the predominant landuse. A significant portion of the riparian forests has been cleared, leaving thin broken corridors, largely infested with exotic species. The Herbert River stream bed typically comprises sand deposits, and banks have loamy or silty soils that are susceptible to slumping.

Case Study Site

The Bube case study site is on a slight bend of the Anabranch channel, approximately one kilometre downstream of its junction with the Herbert River (Plates 1 and 2). Sections of the bank have failed due to slumping. Geotechnical conditions consist of relatively permeable alluvium interspersed with sand lenses, overlying a less permeable substratum. Substantial seepage flows occur from the permeable strata at the base of the slumps during and after rainfall and flood events. Sugarcane cultivation closely abuts the bank and the remnant of the native riparian forest is badly degraded and invaded by exotics.

Remedial works were implemented at the site following bank failure in a flood in February 1994. The objectives of this work were to stabilise the bank and limit further loss of agricultural land, to restrict the likelihood of the channel enlarging and capturing the Herbert River, and to rehabilitate the riparian vegetation. The site was also developed as a trial for monitoring and demonstration of stabilisation and rehabilitation works. This formed part of a research and development project to determine the causes and attributes of the common slumping failures on the lower Herbert River; and to investigate alternative innovative methods of treatment of slump failures.

Strategies & Treatments

Four different treatment designs were installed over an approximate 300 metre length of slumped bank (Figures 2 and 3, Plate 3, and list below). A section of relatively stable, untreated bank with some native vegetation was also retained. Each treatment included a 10 metre wide revegetated strip on the top of the bank where the landholder released the land from cultivation. The treatments were:

Treatment 1	rock revetment, longitudinal subsurface drainage, bank battering & revegetation
Treatment 2	rock revetment & revegetation (rock placed from within the stream)
Treatment 3	revegetation
Treatment 4	lateral subsurface drainage (installed by directional drilling form top of the bank)

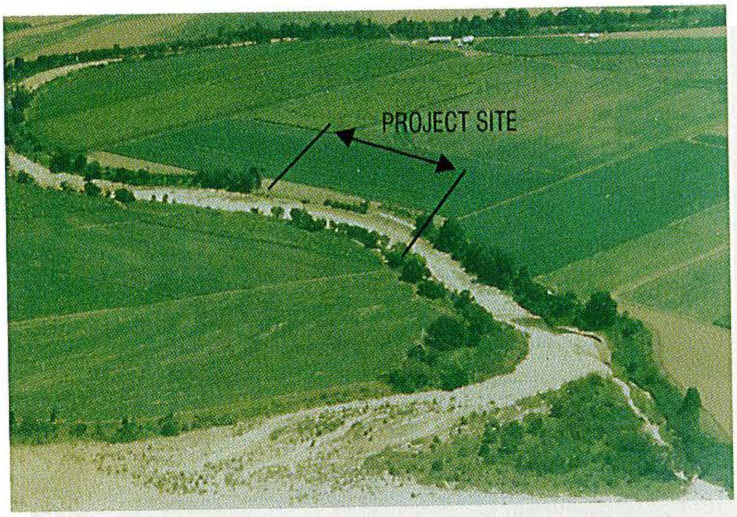

Plate 1 Aerial view of site; Herbert River in the foreground

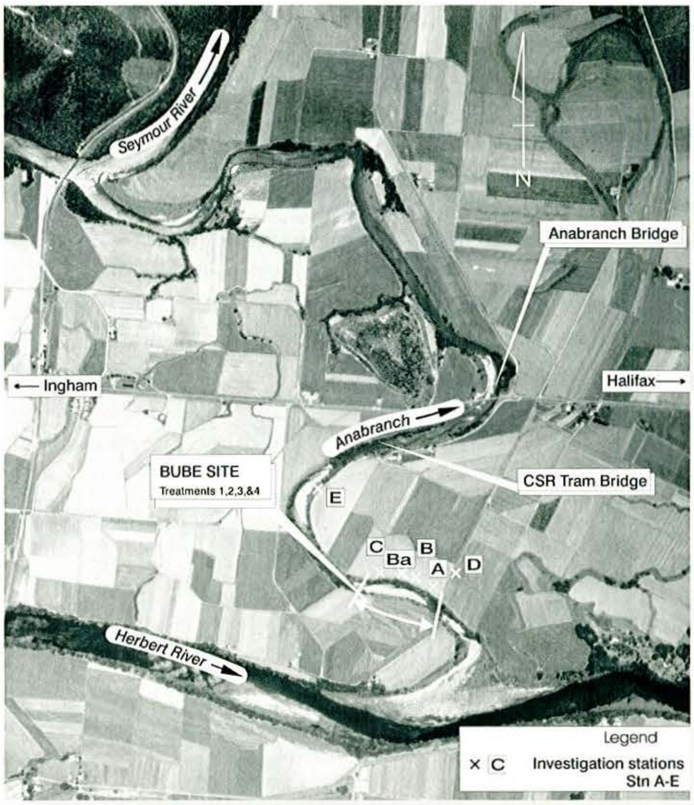

Plate 2 Herbert River Anabranch Bube Locality Plan
Source: Sunmap aerial photo, Ingham 1993, Run 3, No. 110

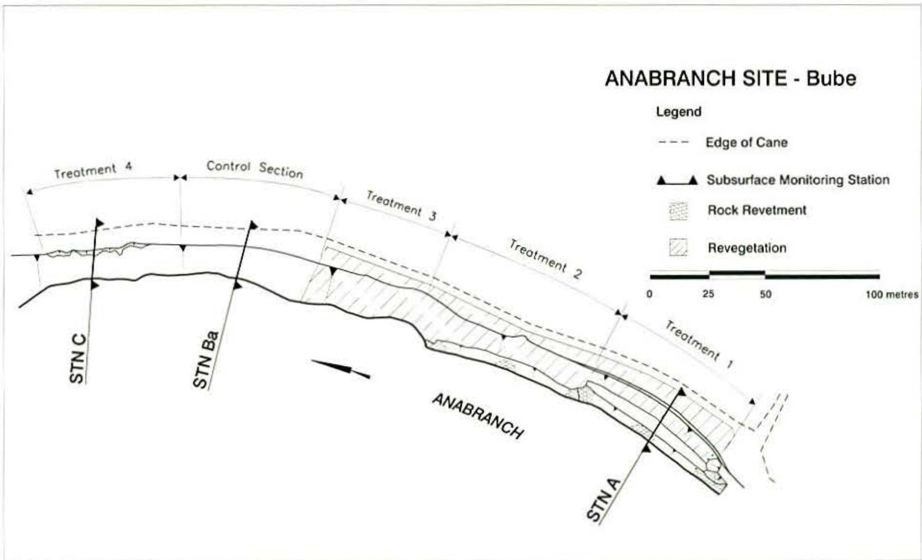

Figure 2 Site Plan

Monitoring & Performance

The trial works were completed in early 1995, and a monitoring program incorporating surveys, measurement of instream water levels, subsurface water levels, pore pressures and moisture contents was implemented. Subsurface monitoring stations were installed in the bank at each of the Treatments 1 and 3 and at the control section. The purpose of these monitoring installations was to investigate the response of subsurface water pressures and soil moistures to rainfall and fluctuations in groundwater and flood water levels, and to observe the relative effects of the alternative drainage systems on these subsurface conditions.

A minor flood event in March 1996 and a moderate flood in February 1997 provided some worthwhile data for the subsurface monitoring program and some performance observations.

The subsurface data has been used to confirm modelling analyses of the effects of flood rise and recession conditions on bank slumping. Monitoring and analysis has shown the merits of subsurface drainage in lowering water levels and reducing the risk of slump failure. More details are provided in Chapter 2 Section 5.

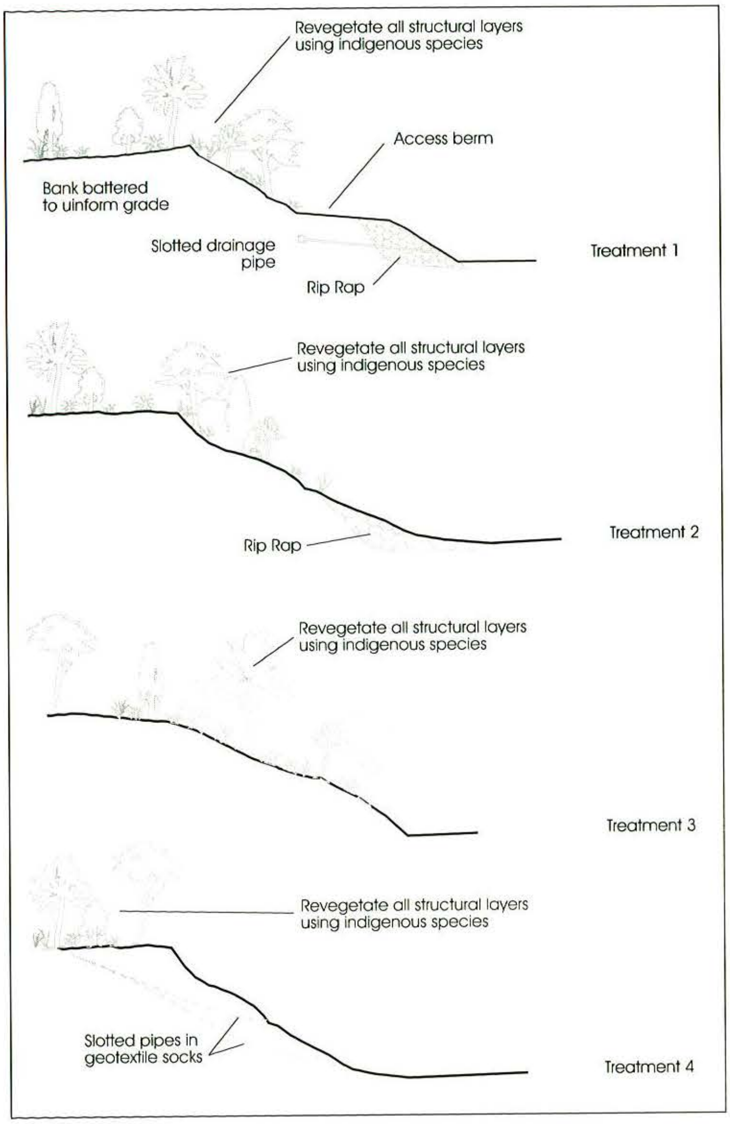

Figure 3 Treatment Cross-sections

Plate 3 Trial stabilisation works; Treatment 1 in the foreground

Summary

The trial stabilisation works have provided useful information on the relative costs and merits of various treatments. The conventional rock revetment and longitudinal subsurface drainage pipe can be used effectively with revegetation of the upper bank (Treatment 1). Rock revetment was successfully placed from within the stream to preserve the existing native vegetation on the bank (Treatment 2). The revegetation (Treatment 3) has performed satisfactorily to date. The lateral subsurface drainage pipes, although relatively expensive in this installation (Treatment 4), was very effective in removing subsurface water and may be a viable treatment for protecting infrastructure in steep sites where access can only be readily obtained from the top of the bank. The monitoring data have assisted in an understanding of subsurface water responses to flood conditions, and in the modelling of streambank conditions. Collaboration with the landholder has enabled reestablishment of a reasonable riparian zone width at the site.

Contributing Organisations

Owner	Herbert River Improvement Trust
Design	James Cook University Ian Drummond and Associates Pty Ltd
Construction (Year)	Herbert River Improvement Trust Wet Tropics Tree Planting Scheme (1994 / 1995)
Monitoring	James Cook University Herbert River Improvement Trust

References

Eckersley, J.D. 1995, 'Geotechnical investigations - Anabranch and Covell sites', in Kapitzke, I.R., Lowry, J.B., Eckersley J.D. & Skull, S.D., *An Investigation into Bank Slumping on the Lower Herbert River,* report prepared by James Cook University for Herbert River Improvement Trust.

Ian Drummond and Associates Pty Ltd 1994, *Design of Trial Bank Stabilisation Works for a Site on the Anabranch,* report to Herbert River Improvement Trust.

Kapitzke, I.R., Lowry, J.B., Eckersley J.D. and Skull, S.D. 1995, *An Investigation into Bank Slumping on the Lower Herbert River,* report prepared by James Cook University for Herbert River Improvement Trust.

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Sands, L.B. (in press), *The Influence of Groundwater Conditions on Streambank Stability in the Wet Tropics,* Master of Engineering Science Thesis, James Cook University, Townsville.

Skull, S.D. 1995, 'An Investigation into bank slumping on the lower Herbert River: Vegetation assessment', in Kapitzke, I.R., Lowry, J.B., Eckersley J.D. & Skull, S.D, *An Investigation into Bank Slumping on the Lower Herbert River,* report prepared by James Cook University for Herbert River Improvement Trust.

Case Study 3
Haughton River Mill Farm

Stream

The Haughton River Mill Farm site is located on the Haughton River adjacent to the township of Giru, approximately 15 kilometres upstream of the river mouth (Figure 1 and Plate 1).

Haughton River Basin Hydrology

Area: 3 650km^2

Mean Annual Rainfall: 923mm

Mean Annual Runoff Volume: 756GL

Maximum Instantaneous Discharge (Jan 1972): 3 964m^3/s

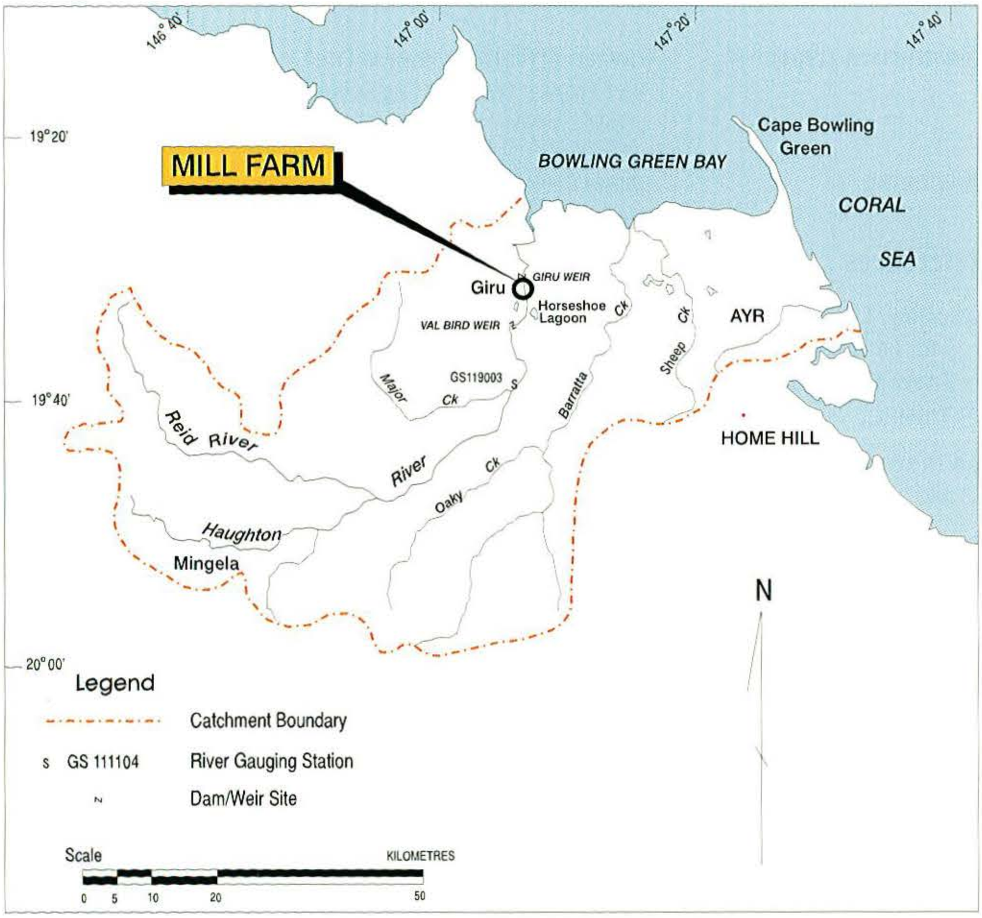


Figure 1 Haughton River Basin

Environment

The Haughton River basin is located entirely in the dry tropics zone and therefore has lower annual rainfall, runoff volumes and runoff depths than wet tropics streams. Nevertheless, the river is subject to severe flooding from tropical cyclones. The Haughton River has distinct downstream-decreasing channel capacity on the floodplain, and experiences major overbank flows that lead to overbank erosion and threats of channel avulsion. Most of the native woodland vegetation on the Haughton River floodplain has been cleared for sugarcane production, leaving thin broken riparian corridors. The river has a sandy bed and non-cohesive bank materials susceptible to fluvial erosion.

Plate 1 Haughton River Mill Farm Locality Plan
Source: Sunmap aerial photo, Ayr 1994, Run 1, No. 59

Case Study Site

The site is located on a slight bend in the river, where erosion on the outside of the bend has threatened channel avulsion and damage to the adjoining agricultural land, the Invicta sugar mill and Giru township. The river bank receded up to 20 metres in the 40 year period prior to 1991. In 1991 a sequence of major floods caused further erosion of approximately 15 metres (Plate 2). Rock groynes were constructed at the site following these floods, with the objective of protecting the bend, limiting further loss of agricultural land and reducing the likelihood of channel avulsion that may result from bank erosion and lowering of bank level.

Strategies & Treatments

Four rock groynes were installed, angled downstream to the bank, with a tapered top profile that sloped away from the bank (Figures 2 and 3, Plate 3). The groynes were adopted in preference to the rock revetment option, which was more expensive, and more likely to require supplementary rock fill at the toe after flood events. The groynes were also preferred to the revetment as they reclaimed the original stream alignment, thus minimising the likelihood of channel change downstream. Furthermore, they retained the riparian land/water interface, thus providing for reestablishment of a healthy riparian zone.

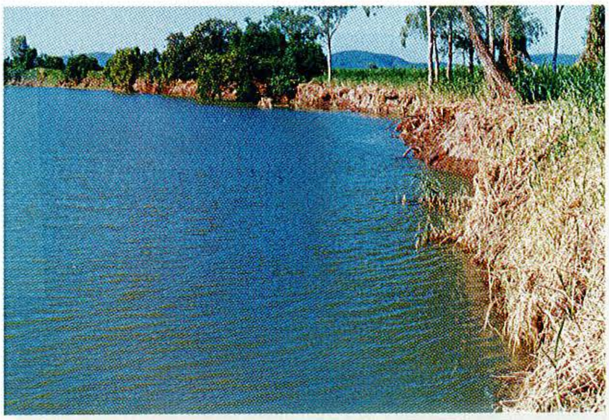


Plate 2 Eroded stream bank prior to construction of rock groynes

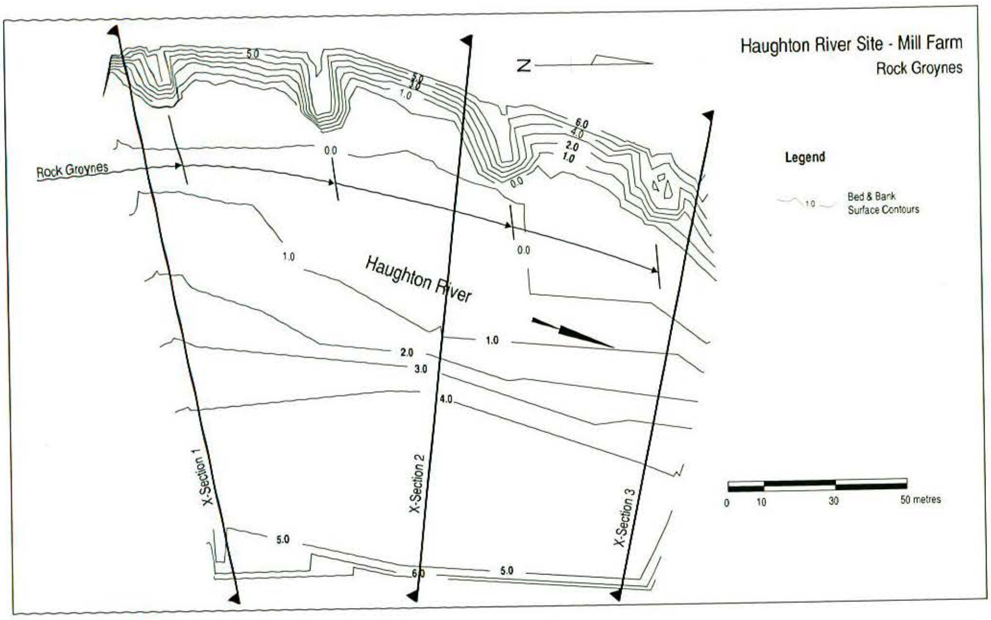
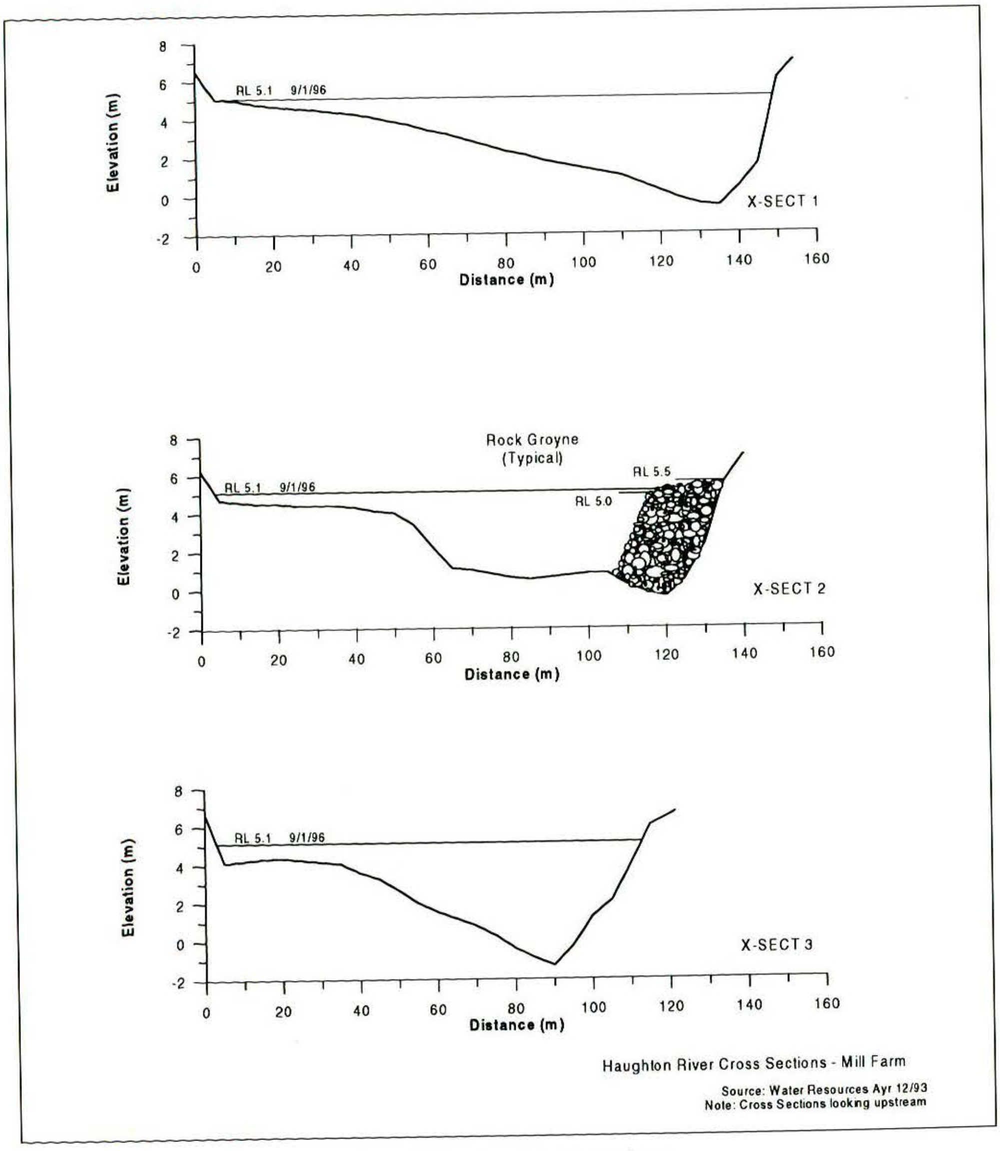


Figure 2 Site Plan



Haughton River Cross Sections - Mill Farm

Source: Water Resources Ayr 12/93
Note: Cross Sections looking upstream

Figure 3 Treatment Cross-sections

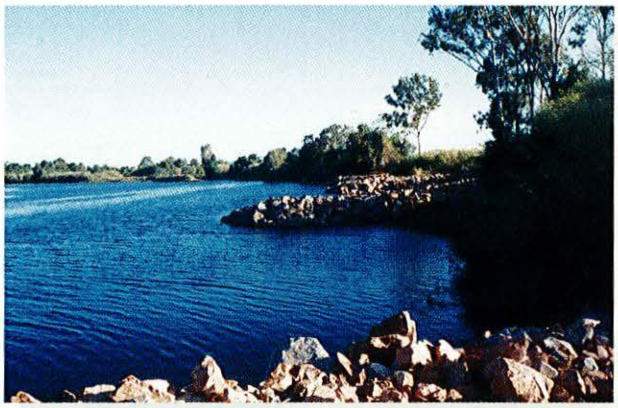


Plate 3 Rock groynes

Monitoring & Performance

The rock groynes are impermeable structures that tend to concentrate flows at the toe of the structure and cause turbulence downstream due to overtopping. They may also affect the downstream flow conditions and cause bank erosion immediately adjacent to the structures. Flow velocities and flow patterns are important for design of the rock fills and in prediction of the sedimentation impacts and alterations to instream habitat between the structures.

The groynes were installed in 1992. The monitoring program since 1993 has focussed on pre- and post-flood bathymetric surveys, and measuring flow velocities and observing flow patterns around the groynes using current meters from a boat. Minor floods in the Haughton River in February 1994 and January 1996, and a more severe event in March 1997 caused no appreciable damage to the site. Flow velocity measurements obtained at low stages registered peak values of 1.5 ms^{-1} at the toe of the groyne. All floods so far experienced are less than the design flood condition.

Summary

The groynes are more suited to the site than the rock revetment option as they are less expensive and have successfully retained the land/water interface. Revegetation of the site is now required to rehabilitate the riparian and instream habitat. Although only limited information has so far been obtained, the monitoring data has assisted in an understanding of flood streamflow velocities within the groyne field. The success of the rock in withstanding the high flow velocities at the toe of the structure, and the effect of the groynes on downstream erosion are of ongoing interest.

Contributing Organisations

Owner	Haughton River Improvement Trust
Design	McIntyre & Associates Pty Ltd
Construction (Year)	Markwell Rockbreaking (1992)
Monitoring	Department of Primary Industries (Department of Natural Resources) James Cook University

References

McIntyre & Associates Pty Ltd 1992, *Mill Farm Bank Restoration Planning Report*, report prepared for Haughton River Improvement Trust, 11p.

Kapitzke, I.R. and Sands, L.B. 1996, *Site Monitoring Report - Physical Component*, Research Report No 5, prepared by James Cook University for the Land and Water Resources Research and Development Corporation.

Case Study 4
O'Connell River Study Site

Stream

The O'Connell River study site is located immediately upstream of the river mouth, approximately 17 kilometres south of Proserpine (Figure 1 and Plate 1).

O'Connell River Basin Hydrology

Area: 2 435km^2

Mean Annual Rainfall: 1 705mm

Mean Annual Runoff Volume: 1 668GL

Maximum Instantaneous Discharge (Jan 1970): 3 265m^3/s

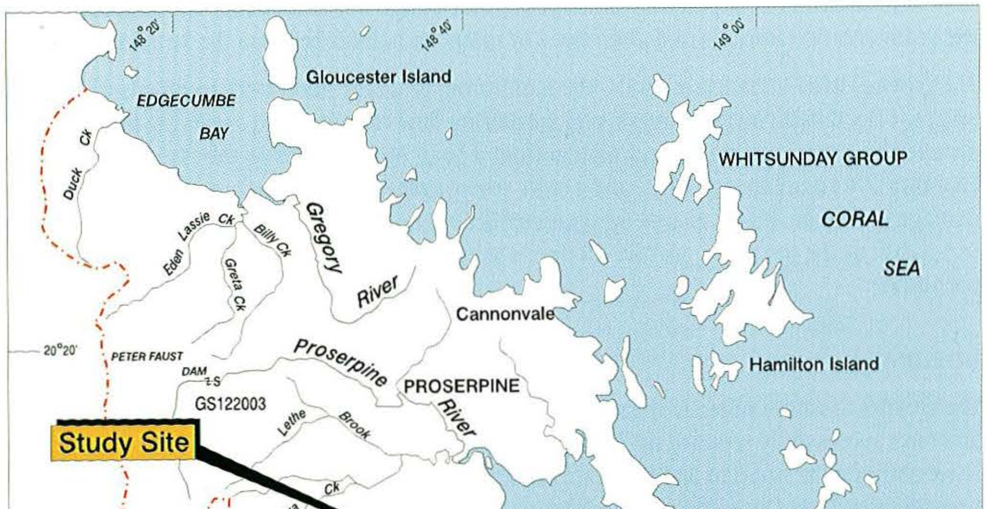


Figure 1 O'Connell River Basin

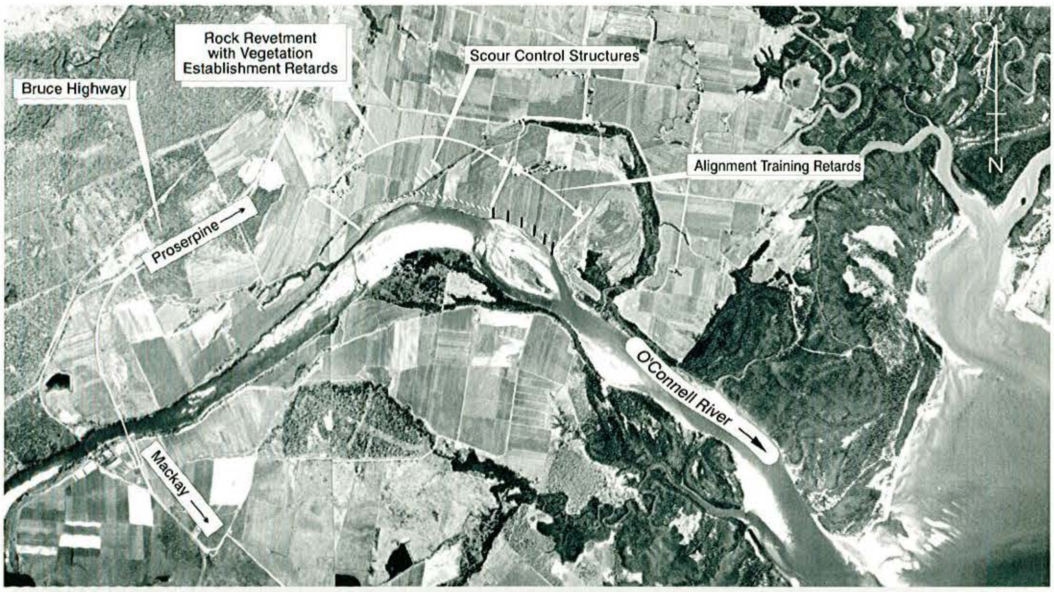


Plate 1 O'Connell River Study Site Locality Plan
Source: Sunmap aerial photo, Calen 1989, Run 2, Nos. 61 and 63

Environment

The site is located in the moist central coast region and experiences summer flooding, characteristic of the north Queensland coastal environment. The O'Connell River floodplain has been extensively cleared for sugarcane farming. The cultivation commonly extends to the very edge of the streambank, thereby destroying the native riparian forest. Cattle grazing is common in the hinterland. The O'Connell River stream bed typically comprises sand deposits, while banks generally comprise non-cohesive silts, sands and gravels. Sand and gravel has been extracted from the O'Connell River upstream of the site.

Case Study Site

The site is located on the O'Connell River estuary on a sweeping bend that is subject to lateral erosion (Figure 2 and Plate 2). The bank has migrated up to 300 metres since 1935, averaging 7 metres per year since 1981, and destroying extensive areas of cultivated sugarcane land. Flooding in 1991 eroded 60 metres of streambank, lowering the natural levee and threatening avulsion into the adjoining depression. Streambanks at the site consist of gravels, interspersed with clay bands, and are subject to fluvial erosion and slumping typical of tidally-influenced alluvial banks. Following the 1991 erosion, the site was completely devoid of vegetation, and faunal species typical of mangrove riparian areas were absent.

Remedial works were implemented at the site in 1996, with the objectives of limiting bank erosion and further loss of agricultural land, restricting the likelihood of a major course change for the O'Connell River, and rehabilitating the mangrove riparian zone. An ecologically-sensitive approach was adopted, and treatment options that would protect the marine habitats as well as meet utilitarian requirements, such as erosion protection, were favoured.

Strategies & Treatments

The remedial works were installed over an approximate 2100 metre length of eroded bank (Figures 2 and 3, Plates 3 and 4). A bank protection strategy using rock revetment (to two-thirds bank height) was adopted for the upstream section, while alignment training retards were adopted for the more severely-eroded downstream section. Vegetation establishment retards were used in conjunction with the rock revetment, with the aim of increasing flow resistance,

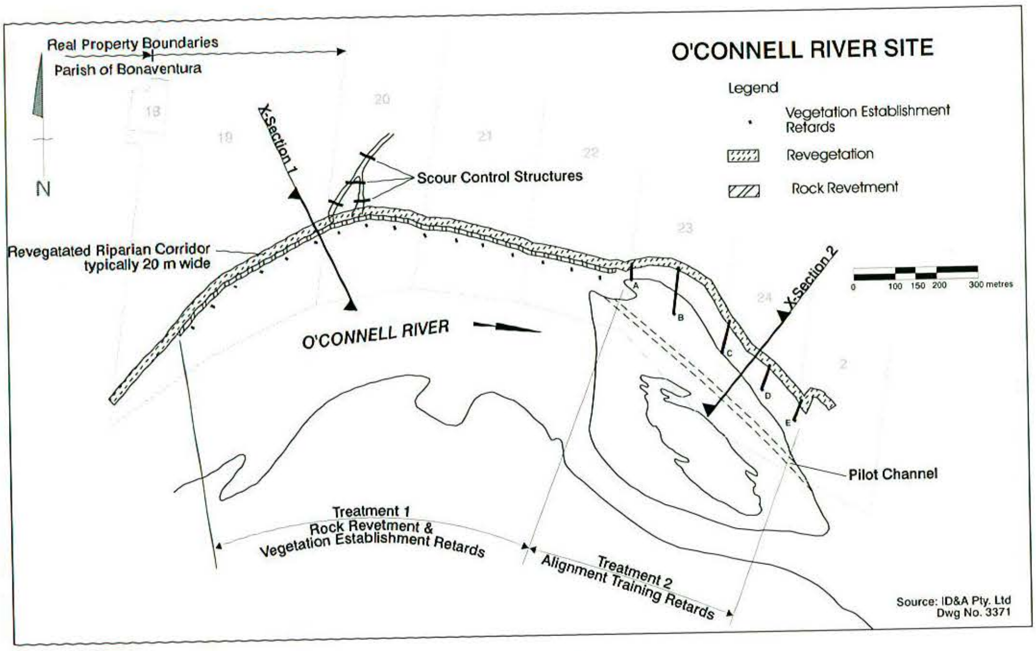


Figure 2 Site Plan

Plate 2 Aerial view of site: Bank erosion extending into cane land on right

encouraging sediment deposition, and enabling permanent vegetation growth. In addition to these functions, the alignment training retards were intended to shift the erosive flow currents away from the bank and reinstate instream habitat. Scour control structures were installed on the flood overflow channel to prevent the river avulsing into the adjoining depression. Each bank protection component included a 20 metre wide revegetated riparian strip where landholders have released the land from cultivation.

Monitoring & Performance

An elementary monitoring program was implemented on completion of the works, to record treatment performance and revegetation establishment progress. A moderate flood in March 1997 caused little damage.

Summary

The rehabilitation program has provided a useful demonstration of how various treatments can be integrated in an ecologically sensitive manner. Rock revetment (lower bank) and revegetation (upper bank) provide a robust and cost-effective treatment for the upstream section of the site. The vegetation establishment retards in this section provide sacrificial support for rehabilitation of instream habitat. The alignment training retards, although more expensive than rock revetment for the downstream section, have been adopted to improve stream alignment and, again, rehabilitate instream habitat. Collaboration with the landholders has enabled a reasonable riparian zone to be reestablished at the site. The effects of these works on restricting further loss of agricultural land, and on alterations to sediment transport and deposition in the river reach and the adjoining marine environment, are of ongoing interest.

Contributing Organisations

Owner	Proserpine (Whitsunday) River Improvement Trust
Design	ID & A Pty Ltd James Cook University
Construction (Year)	J. J McDonald & Sons Engineering Pty Ltd Giles Contractors Pty Ltd (1996)
Monitoring	Proserpine (Whitsunday) River Improvement Trust

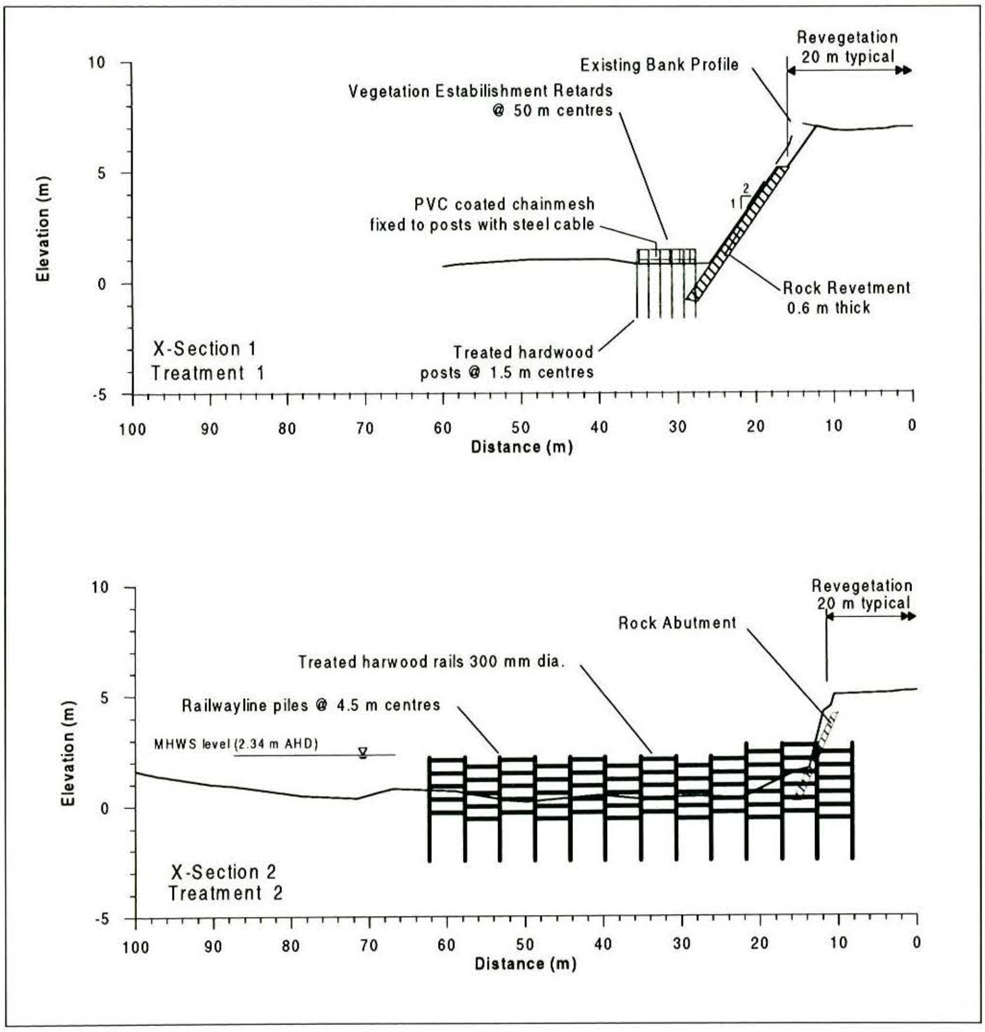


Plate 3 Rock revetment

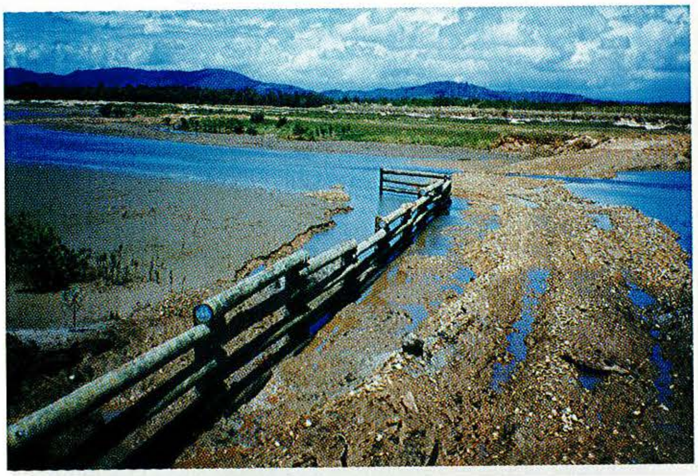


Plate 4 Retard

References

Clayton, P.D. and Skull, S.D. 1996, *Bank Stabilisation Design Options and Implementation on the Lower O'Connell River: Ecological Aspects,* final report prepared by Australian Centre for Tropical Freshwater Research for ID & A Pty Ltd.

ID & A Pty Ltd 1996d, *O'Connell River Bank Stabilisation Project Design Summary,* report to the Proserpine River Improvement Trust.

Oates, J. 1993, *O'Connell River: Evaluation of a Project for Control of River Erosion,* report prepared by Ian Drummond and Associates Pty Ltd, 43p.

Appendix A - Pressures on the Streams

Pressures relate to human activities that affect the stream environment. Direct pressures occur on the stream channels and adjoining riparian lands. Indirect pressures occur within the catchment but remote from the stream.

Summary descriptions and examples of pressures on north-east Queensland coastal streams are presented in Table 1.2 in Chapter 1.

Table 1.4 in Chapter 1 indicates the likely relationship between individual stream management problems and pressures on the streams.

Direct Pressures

- Flow Regulation, Water Storage and Diversion
- Channelisation
- River Works
- Aggregate Extraction and Mining
- Encroachment from Agriculture, Urbanisation and Infrastructure
- Recreation and Boating
- Introduction of Feral Animals, Exotic Fish and Plant Species

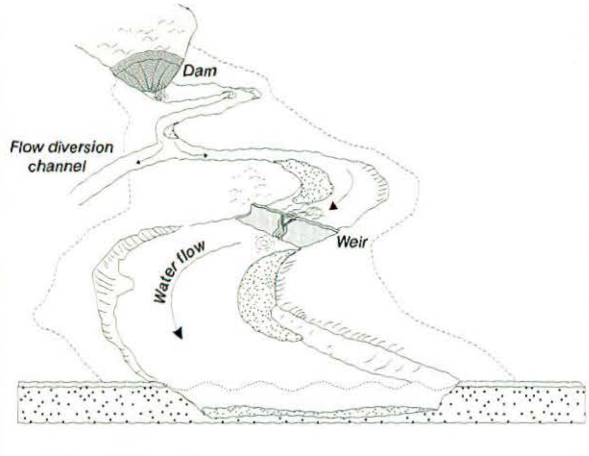
Indirect Pressures

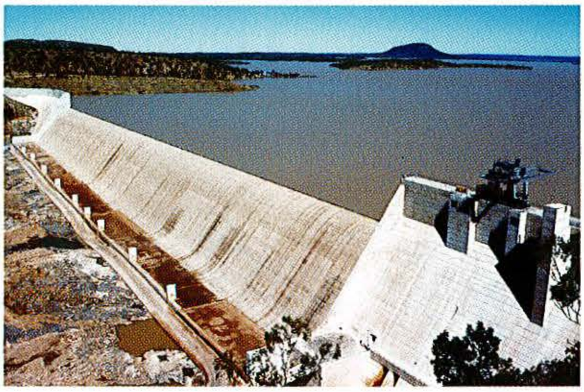
- Modified Water and Sediment Flow Regimes from Catchment
- Pollution with Biocides, Heavy Metals, Nutrients etc

Pressure Description

Flow Regulation, Water Storage and Diversion

Direct Pressure





Burdekin Falls Dam on the Burdekin River

Flow regulation, water storage and diversion involve the construction of dams, weirs, pumping schemes and diversionary channels (which remove water from the stream system or transfer it between basins) for water supply, irrigation, hydro-electric power or flood control. These activities modify the downstream flow regime and may affect the upstream and downstream flow mechanics and the stream ecology. Water storages reduce the sediment load passing downstream, and the corresponding increase in sediment-carrying capacity may cause downstream bed and bank degradation. The stream ecosystem may be affected by changes in total annual discharge, flood frequency, drought frequency, flow duration, seasonality, velocity, and rate of rise and fall. The changed flow regime may cause drying out of perennial streams, with devastating effects on biodiversity. Conversely, higher flows may be delivered at times when natural flows are minimal, again with devastating effects. Flow regulation, water storage and diversion installations can affect rates of channel change, channel form, sediment transport, water quality, habitats, biota and fish passage. Flow regulation is one of the most significant modifications to stream ecosystems, with the capacity to change biological communities, eliminate species, reduce habitat diversity and disrupt biological processes linked to floods and/or droughts.

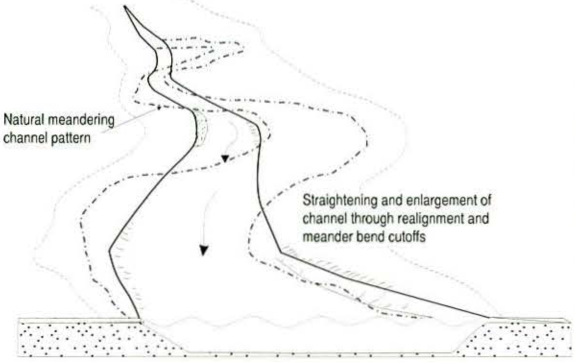
Pressure Description

Channelisation

Direct Pressure

Agricultural drain near Tully

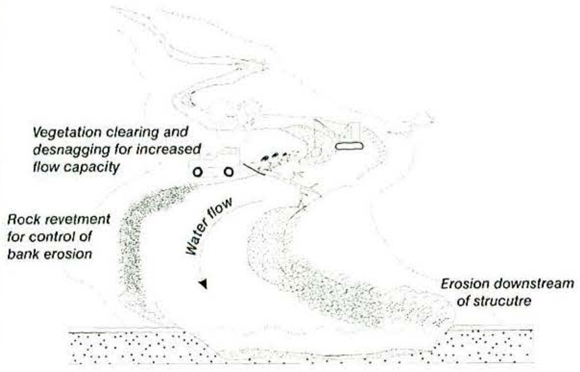
Urban drain in Townsville



Channelisation is the straightening and enlarging of stream channels for the purposes of navigation, erosion control, drainage, and re-alignment at bridge crossings. It may involve channel widening and meander cutoffs in larger streams, realignment of smaller streams and open and piped drain construction. These modifications increase flow velocities and the number and magnitude of high flows downstream, and often accelerate bank and bed erosion. The channel slope increases through the shorter channel path, the ability to transport sediment increases with increased velocities, and bed degradation progresses upstream, possibly causing bank collapse. The excess sediment load is then deposited in the natural reach downstream of the channelised section. Stabilisation works are commonly implemented following channelisation, in an attempt to prevent the stream regaining its original slope through bedform and meander growth. Channelisation commonly has major ecological impacts on the aquatic biota and the linear terrestrial habitat of the stream channel and downstream reaches. Habitat diversity is reduced as the natural meandering stream and its riparian vegetation are altered and the variety of channel bed forms and flow configurations is reduced. Biological productivity and diversity are reduced by the instability of substratum, water temperatures and water levels; the higher-than-tolerable velocities; the loss of natural sorting of streambed material; and the destruction of streambank vegetation.

Pressure Description

River Works
Direct Pressure



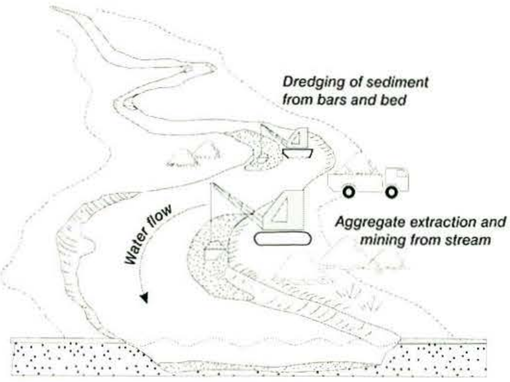
Rock revetment on the Herbert River: note gap in riparian vegetation

Traditional river 'improvement' works include bank stabilisation and alignment training works for control of local bank erosion, levee banks for flood control, and channel clearing and desnagging for increased streamflow capacity and erosion control. Whilst generally undertaken with the good intention of protecting public or private assets, these traditional 'hard' river engineering methods have frequently been carried out in a piecemeal fashion that has caused further problems. Protection of one section of stream bank often leads to erosion at an adjoining site. Levees separate streams from their floodplains and increase the risk of catastrophic flood damage if they fail, and channel clearing and desnagging can damage riparian and in-stream vegetation and remove important habitats. Whilst providing improved streambank stability, river works may change streamflow characteristics, increase erosion, introduce exotic plants, fragment riparian habitats and interrupt faunal corridors. Loss in fish and wildlife habitats, reduction in habitat diversity and degradation of aesthetically pleasing stream qualities may result. Unless very carefully implemented, river works may be expensive but temporary local and partial solutions to a long-term and extensive problem.

Pressure Description

Aggregate Extraction and Mining

Direct Pressure



The effects of aggregate extraction in the Gregory River near Proserpine

Aggregate (sand and gravel) extraction and dredging are in-stream activities that may cause physical and biological degradation of the stream. Aggregate extraction commonly creates discontinuities in bedload movement in the stream, increases channel cross-sectional area, decreases stream velocity and increases deposition at the site. It may accelerate sediment delivery from upstream, leading to erosion, and may create a sediment deficit downstream, also leading to erosion. Extraction changes stream channel morphology. The physical and biological function of the stream bank is affected by bank instability that may result from the changed sediment regime or disturbance to streambank vegetation. Excess sediment may enter the stream, riparian and in-stream habitats are typically degraded, the downstream water quality is lowered, and the ecology of the tidal zone is affected if the hydrodynamics of the tidal prism are altered. Other adverse effects from aggregate extraction may include lowering of floodplain water tables, reduced frequency of overbank flow and wetland inundation, changed bed material size composition, destruction of aquatic and riparian vegetation, increased bar mobility, loss of sediment supply to beaches and greater frequency of substratum mobility.

It is possible that, in some situations, extraction of sediment can improve habitat values by removing excessive non-natural sediment build-up, and restoring deep water holes as important habitats. The possibility of such benefits would be determined on a case-by-case basis, and planning and design would need to consider all relevant geomorphic, hydrological and ecological factors.

In-stream mining for minerals such as gold or tin can have a significant effect on a stream. Although alluvial mining is not commonly practised today, in Australia's pioneering days, large companies operated mechanical dredges that reworked enormous quantities of sediment both in the streams and on the floodplains. Alluvial mining by excavation or by hydraulic means disturbs the channel morphology, mobilises fluvial sediments and greatly increases sediment load in a stream as a result of channel erosion and dumping of sediments and mine tailings. This, in turn, adversely affects water quality, in-stream and riparian habitat and stream channel biota.

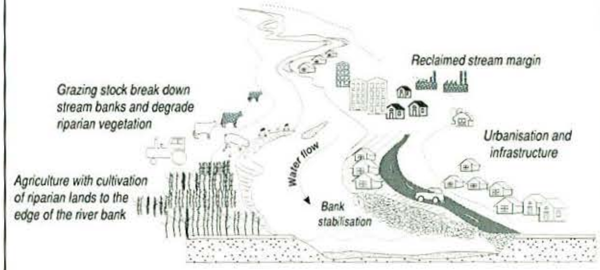
Pressure Description

Encroachment from Agriculture, Urbanisation and Infrastructure

Direct Pressure

Urbanisation on the Ross River in Townsville

Complete removal of riparian vegetation on the South Johnstone River near Innisfail

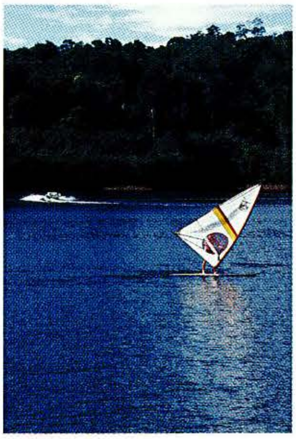


The encroachment of agriculture, urban development and infrastructure on to streams and their floodplains produces a number of problems. These may result from modification of drainage systems, relocation and filling of minor streams, and expansion of agricultural, residential and industrial developments adjacent to major streams. In agricultural areas, farmers commonly clear and cultivate the riparian lands to the very edge of streams, spray and burn the riparian vegetation, and use farm management practices that may adversely impact on the stream and on any remnant vegetation in the riparian zone. Grazing stock often break down stream banks and degrade the riparian vegetation, further reducing the link between the stream and the floodplain. Urban waterways are reshaped, lined and otherwise transformed into functional and/or culturally desirable landscapes to provide for increased streamflow, transportation, recreation, tidiness and maintenance. Habitat is removed and the native vegetation and wildlife corridor is broken, thus contributing to the overall degradation of the riparian zone. Infrastructures, such as freeway embankments are constructed across the floodplains, while bridges, culverts and buildings encroach on stream channels. These encroachments on streams and riparian lands have contributed to extensive stream degradation by increasing streambank instability, local runoff and erosion, and decreasing water quality through accelerated pollution and sediment input. They have also degraded riparian lands; caused infestation with exotic plants and animals; fragmented, isolated or eliminated the natural riparian vegetation corridor; replaced wildlife habitats with low-grade habitats; and reduced the abundance and diversity of aquatic and terrestrial organisms.

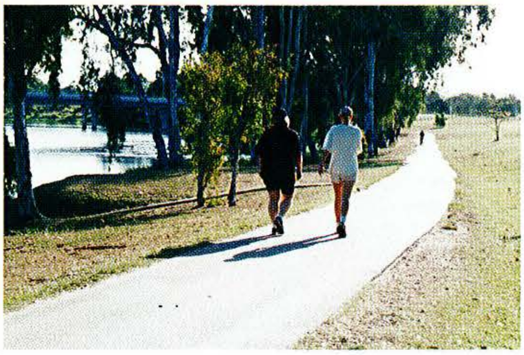
Pressure Description

Recreation and Boating

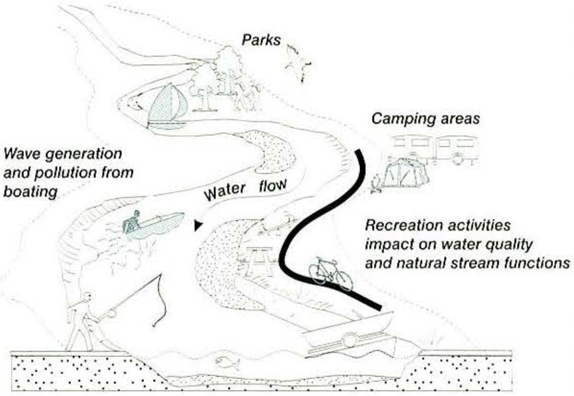
Direct Pressure



Power boating and sail boarding on Paluma Dam near Townsville



Riverfront land altered for recreation on Ross River, Townsville

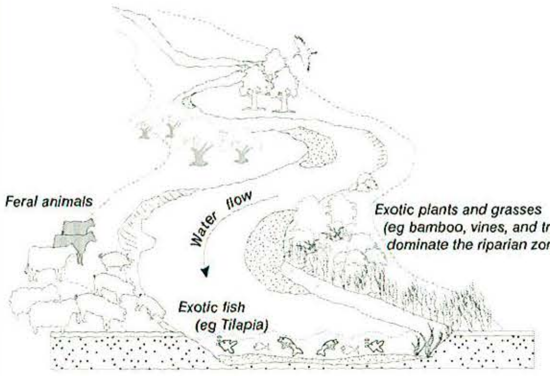


Recreation facilities such as camping areas, parks, and playgrounds often encroach on streams, and contribute to the destruction of native vegetation and the alteration of streambanks. Recreation activities may impact on water quality and natural stream functions both local to, and remote from, the recreation site. Boating may cause physical disturbance at the boat access point and this may degrade water quality, particularly as a result of oil-based contaminants. Wave-generated erosion of streambanks is one of the most significant detrimental impacts of boating.

Pressure Description

Introduction of Feral Animals, Exotic Fish and Plant Species

Direct Pressure



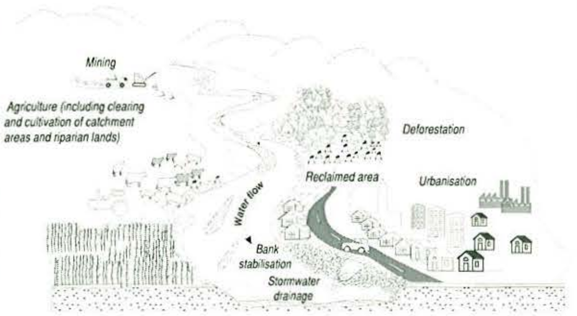
Exotic plants on Herbert River near Ingham

Exotic species of plants and animals may be introduced to the streams by agriculture, urban development, industry and recreation activities. Feral animals such as pigs, goats and rodents can degrade riparian vegetation and cause bed and bank instability and habitat destruction. Lowland streams are more likely to be affected by species of introduced plants and fish than are upland streams. Exotic fish such as Tilapia, and exotic species such as the cane toad and others, can dominate instream and terrestrial fauna, may act as disease vectors, and can degrade in-stream and riparian habitat, leading to bank instability, bed erosion, sedimentation and changes in nutrient status and algal blooms. Exotic plants such as Bamboo that have been sometimes planted on streambanks to improve stability, can develop into monocultures that invade the riparian zone, dominate natural plant species and destroy native fauna and flora habitats. Exotic plants tend to flourish in areas of degraded native flora and may choke the stream waterway, increase sedimentation, modify stream hydraulics and morphology, and reduce bank stability (because many weed species are shallow rooted). Exotic aquatic plants commonly decrease light penetration in the stream and diminish water quality, causing declines in the diversity and abundance of native submerged plants and impacting on aquatic fauna. Weeds such as Para Grass impede normal flows, significantly altering stream cross-sections, thereby reducing natural habitat diversity.

Pressure Description

Modified Water and Sediment Flow Regime

Indirect Pressure



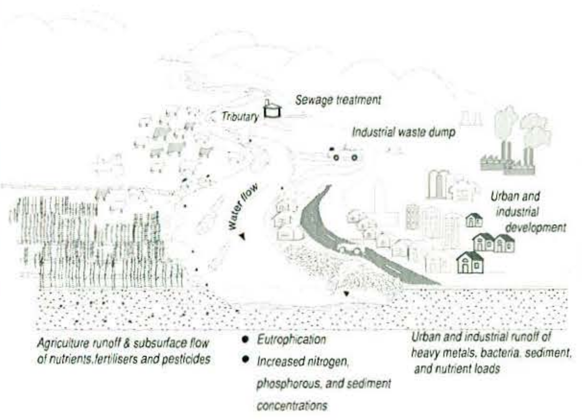
Clearing of catchment and riparian zone for grazing

Water and sediment flow regimes are modified by catchment activities such as agriculture, forestry, mining and urban development. Increased erosion, changed water and sediment yields, and increased nutrient runoff commonly result from clearing and cultivating catchment areas and riparian vegetation for agriculture. Agricultural practices may include draining and reclaiming low-lying areas, wetlands and tidal lands; farming steep areas; constructing farm dams; implementing soil conservation measures, water harvesting, and irrigation; and planting crops. Clearing and irrigation bring about the salinisation of soils, wetlands and streams; and cattle grazing causes increased runoff, raised nutrient levels, accelerated erosion and sedimentation from the disturbance and compaction of soils. Deforestation and logging cause increased runoff, gullying and increased sediment loads unless forestry operations are carefully managed. Clearing and construction for urban development temporarily increase erosion and sedimentation but this is subsequently reduced locally as impervious surfaces are installed. Agriculture, mining and forestry generally increase runoff volumes, runoff peaks and sediment yield and reduce flood duration, whereas urban development decreases the time to flood peak, increases the magnitude and frequency of high flows, decreases base flows, and reduces sediment delivery. The overall effect of these catchment changes on the streams is that stream channels aggrade; flood levels increase; water quality declines; stream turbidity increases; channel form is simplified through change; substrata are altered; life cycles and behaviour of stream biota are affected; and species diversity and productivity in the aquatic and riparian ecosystems are reduced.

Pressure Description

Pollution with Biocides, Heavy Metals, Nutrients etc

Indirect Pressure



Effluent disposal from sugar mill

Streams may be polluted by mixtures of organic and inorganic pollutants from diffuse (indirect impact) or point-source (direct impact) discharges associated with agriculture, and with urban and industrial development. Surface water runoff from agricultural land causes stream sedimentation and chemical pollution from fertilisers and pesticides. In addition, nutrients such as nitrogen may enter the stream by percolation into the groundwater. Phosphorus is bound to the soil particles and is mainly transported via surface runoff, and most nutrients enter as sudden events or pulses. Urban runoff commonly contains noxious heavy metals and harmful bacteria as well as increased sediment and nutrient loads. Discharges from sewage treatment, sugar mills, other industrial plants, and waste dumps may contain solid waste, toxic chemicals and excess organic matter, and may alter instream temperatures. The sediments, nutrients and other pollutants are exported downstream and may affect the physical, biological and chemical function of instream, riparian, wetland, estuarine and marine areas (eg. The Great Barrier Reef World Heritage Area). This may lead to eutrophic stream conditions with high rates of biological activity; increased nitrogen, phosphorus and sediment concentrations; altered nutrient dynamics; altered riparian vegetation; habitat reduction; impoverished plant and animal life; introduction of exotic species; contamination of water supplies; and reduced recreational value.

Appendix B - Stream Management Problems

Stream management problems occur where the stream's natural physical and ecological functions conflict with human use. Problems may arise from natural processes or they may be human induced.

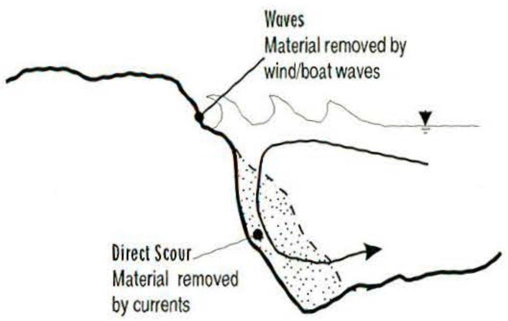
Summary descriptions and examples of problems on north-east Queensland coastal streams are presented in Table 1.3 in Chapter 1.

Table 1.4 in Chapter 1 indicates the likely relationship between individual stream management problems and pressures on the streams.

- Fluvial Bank Erosion
- Mass Movement
- Overbank Erosion
- Bed Erosion
- Sedimentation
- Channel Avulsion
- Riparian Habitat Degradation
- Instream Habitat Degradation
- Degraded Water Quality
- Altered Flood and Flow Regime
- Loss of Land, Utility and Infrastructure
- Reduced Recreation Value
- Reduced Conservation Value

Problem Description

Fluvial Bank Erosion



Bank erosion affecting sugar cane land on Mossman River near Mossman

Description

Fluvial bank erosion (scour) is the removal of streambed and streambank materials by water flowing in the stream or by wave action. It is caused by the tractive force of water on the bank material. The principal type of fluvial erosion is direct scour of bank and bed materials by streamflow that undercuts the toe of the bank, strips surface soils from the face of the bank, or scours the stream bed, leading to undermining of structures (eg. culverts) or the banks. Fluvial erosion also results from waves generated by boats or wind.

Pressures

- flow regulation facilitiies, such as dams that trap sediment and create a local sediment deficit in downstream flows
- channelisation such as channel straightening, clearing of instream obstructions, and bend cutoffs
- aggregate extraction and mining
- infrastructure such as bridges, culverts and weirs that create local disruptions to flow patterns
- encroachment on the stream by agriculture (eg. clearing and cultivating banks), grazing (eg. cattle accessing water in the stream), and urban developments (eg. stormwater discharge)
- recreation activities (eg. boat generated waves, camping that destroys vegetation and disturbs the bank)
- infestation by exotic species (eg. pigs disturbing banks, rubber vine killing native vegetation)
- catchment clearing that increases the rate and quantity of water entering the stream

Potential Causes

Hydrological & Hydraulic

- the high water levels and high flow velocities associated with flood conditions generally cause the majority of fluvial erosion, although in estuarine areas, for example, regular tidal flows may cause gradual erosion that can accumulate to a significant proportion of total erosion
- reduced retention and infiltration of rainfall, and more rapid runoff from catchments that have been cleared and drained result in floods that are larger than they would have been naturally, and so have greater erosive power
- the naturally sporadic nature of large flow events in the region may result in periods when there are few large flows and minimal erosion, contrasted with periods when a number of large flows are close together and combine to compound erosive effects
- a change in flow patterns, for example caused by bridge piers or groynes, can direct the erosive forces onto other sections of bank
- changes to the flow pattern that result from constrictions and obstructions (eg. culverts, weirs, bridge piers, tree trunks, snags) can produce high flow velocities that can cause severe local erosion
- wave erosion at the waterline can cause steepening and undermining of banks

Geomorphological & Geotechnical

- soils that become wet or saturated as a result of rainfall or flood inundation, generally lose strength and become more susceptible to fluvial erosion
- low clay content bank soils (silty to sandy) have low cohesion and are susceptible to entrainment
- fluvial erosion occurring naturally on the outer bank of meander bends can be accelerated by pressures that increase the erosive power of the stream or reduce the erosion resistance of the bank
- changes in bed slope, resulting from channelisation or bend cutoffs for example, lead to increased sediment transport capacity and a consequent increase in erosive power

Ecological

- erosion can be exacerbated by a lack of riparian vegetation, which in natural systems would bind the bank material and provide a protective barrier between the flowing water and the soil

Possible Consequences

Geomorphological & Geotechnical

- mass bank failure
- lateral channel migration
- channel avulsion
- downstream sedimentation

Ecological

- instream habitat degradation
- riparian habitat degradation
- water quality degradation
- reduced conservation value
- all consequences listed under 'Riparian Habitat Degradation'

Human Use

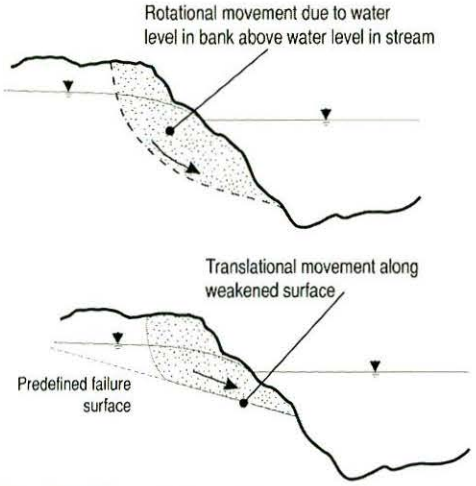
- reduced recreation value
- loss of land
- damage to infrastructure

Comments

Fluvial bank erosion is a natural or human induced process that is closely linked to hydrological, and sediment transport and deposition processes. The rate and extent of fluvial erosion can be greatly accelerated by human activities that alter the characteristics or quantities of flow or sediment, or result in disturbance to the riparian area. Native vegetation usually enhances the protection of banks against erosion, although fallen timber may temporarily exacerbate erosion locally.

Problem Description

Mass Movement



Slumping on Herbert River Anabranch near Ingham

Description

Mass movement (slumping) refers to the bulk movement of streambank material that occurs when soil strength along a failure surface is inadequate to resist the weight of overlying material and surcharge loads on the bank. Mass movement occurs naturally, but can be exacerbated and accelerated by pressures that alter the morphology, material properties, vegetation, moisture balance etc. of the bank. Principal modes of mass movement include:

- retrogressive, where relatively small scale failures occur progressively up the bank and result in a combined failure of greater magnitude
- rotational, where the mass slides along a circular failure surface
- translational, where the mass slides along a planar failure surface
- compound, where a combination of rotational and translational movements occur
- piping, where groundwater flow removes fine soil particles and undermines a section of the bank
- toppling, where the mass topples away from the remaining bank, often as a result of undercutting
- creep, where very slow translational movement of the soil mass occurs.

Pressures

- aggregate extraction can lead to bed lowering and possible bank undercutting and oversteepening
- encroachment on the stream by agriculture (eg. clearing and cultivating banks), grazing (eg. cattle grazing on the banks, traversing banks to access water in the stream), which can alter soil moisture and reduce strength properties
- bank modifications, such as earthworks to provide vehicle access
- clearing of riparian vegetation, which can alter the moisture balance and strength properties of the bank
- recreation activities on the stream bank (eg camping and picnicking that disturbs bank materials and damages vegetation)
- infestation by exotic species (eg. pigs disturbing bank material, exotic weeds killing native vegetation)
- catchment clearing that increases flood levels and changes the rate of flood rise and fall

Potential Causes

Hydrological & Hydraulic

- saturation of bank due to rainfall or flood inundation, contributing to increased weight and decreased strength of material
- rapid recession of floodwater which leaves the bank soils wet, heavy and weakened and without the support of the stream water

Geomorphological & Geotechnical

- oversteepened banks caused by, for example, toe scour, erosion from wave action, excavation
- undermining by erosion of less resistant layers low in the bank
- undermining by piping erosion as subsurface water discharges through the bank
- sliding along a geologic weakness or discontinuity such as a weak clay layer
- silty/fine sand can lose almost all strength on becoming saturated
- build-up of pore pressure due to saturation of the bank, blockage of drainage mechanisms, water pressure in tension cracks etc.
- reduced strength of the bank slopes and increased entry of water due to the removal of riparian vegetation

Ecological

- disturbance from non-native animals, such as access tracks made by cattle and grubbing by pigs, changing the strength and infiltration characteristics of the bank
- native species replaced by exotic species which have inferior stabilisation properties

Human Use

- surcharge from infrastructure, vehicles, stockpiles that causes an unstable situation as the soil becomes wet and loses strength

Possible Consequences

Geomorphological & Geotechnical

- fluvial bank erosion
- sedimentation
- channel avulsion

Ecological

- riparian habitat degradation
- instream and underbank habitat degradation
- water quality degradation
- reduced conservation value

Human Use

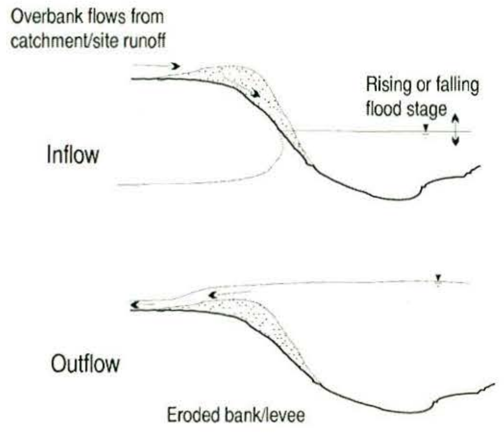
- reduced recreation value
- loss of land
- damage to infrastructure

Comments

Failure surfaces are generally shallow in non-cohesive banks and deep in cohesive banks, with shallow slump failures common in silty sandy banks in north-east Queensland. Shallow failures may be retrogressive, whereas failures in cohesive banks are generally deep, and often occur along weak surfaces. Diverse native vegetation on the banks improves overall bank strength.

Problem Description

Overbank Erosion



Overbank erosion from flood outflow on Haughton River near Giru

Description

Overbank erosion is the removal of material from the bank and close to the bank by water that flows from the stream on to the floodplain, or from the floodplain into the stream. The erosion caused by flows entering the stream is referred to at different scales as rilling and gullying.

Pressures

- channelisation, which may increase flood capacity in one reach of the stream but cause higher water levels and more damaging overbank flows in other reaches
- aggregate extraction causing damage and possible lowering of banks
- encroachment on the stream by agriculture (eg. clearing and cultivating banks and adjacent floodplains), grazing (eg. cattle traversing the banks to access water in the stream), urban developments (eg. stormwater discharge)
- recreation activities on the stream bank (eg camping and picnicking that disturbs bank materials and damages vegetation)
- infestation by exotic species (eg. pigs disturbing bank material, exotic weeds killing native vegetation)
- catchment clearing resulting in increased flood levels

Potential Causes

Hydrological & Hydraulic

- outflows occur during high level flood flows
- inflows are usually associated with local rainfall events that may occur while stream levels are low, or occur as stream levels recede after a major inundation and the floodplain drains back to the stream
- outflows and associated erosion are exacerbated by any effects that lower bank levels (eg. access track, stream crossings, cultivation, trenching for pipes or drains), or any effects which increase flood levels (eg. levees in other places, catchment drainage, urban development, obstructions in the stream)
- activities which reduce resistance to flow out of the channel (eg. floodplain clearing, unplanted fields, drains, roads, unvegetated banks) increase the damage by outflows
- inflow damage is often the result of changes to local drainage (eg. drainage changes for agriculture, concentration of drainage under roads, road table drains)

Geomorphological & Geotechnical

- changes in bed slope, resulting from channelisation or bend cutoffs for example, lead to increased sediment transport capacity and a consequent increase in erosive power
- unprotected and unconsolidated soils (eg. unvegetated banks, cultivated fields) are more susceptible to damage by outflows
- piping erosion through levees (both natural and constructed) can initiate erosion that effectively lowers the bank and allows overbank flow
- overbank erosion can be cumulative and accelerating - one episode lowers the bank a little, the next episode occurs at a lower flood level and further lowers the bank etc.

Ecological

- removal of vegetation on the banks and on the adjacent lands provides less resistance to water leaving the channel and so allows higher velocities and increased erosion

Possible Consequences

Geomorphological & Geotechnical

- mass bank failure
- downstream sedimentation
- gullying
- floodplain stripping where flows are concentrated
- avulsion

Ecological

- riparian and instream habitat degradation
- water quality degradation
- reduced conservation value

Human Use

- reduced recreation value
- loss of land close to the stream
- damage to land close to and remote from the stream
- damage to infrastructure

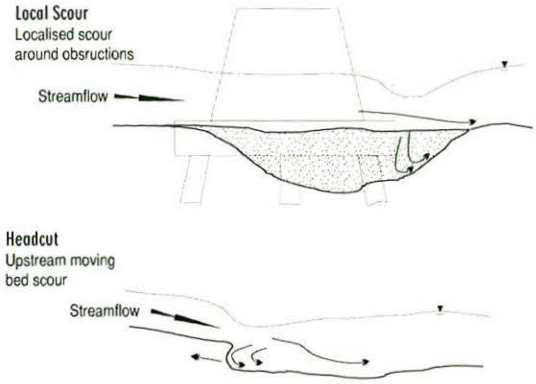
Comments

Overbank flow is commonly a natural process, and is an ecological necessity on floodplains, replenishing wetlands with water, and soils with new sediments. Human activities that affect the natural drainage and the natural vegetation tend to concentrate overbank flows, which may occur at lower flood levels or from smaller rainfall events. Activities that leave soils unprotected (eg. unplanted fields, disturbed banks) during the flood season can significantly increase the damage caused by overbank flows.

Problem Description

Bed Erosion

Streambank & Streambed Instability



Creek erosion at culvert outlet in Townsville

Description

Streambed erosion is the removal of bed materials by water flowing in the stream.

The predominant types are:

- local scour, which results from increased turbulence and increased velocities occurring at obstructions such as bridge piers, snags, weirs etc.;
- headward erosion (headcut), which occurs when there is a 'step' in the bed level that provides an excess of energy in the flow, and hence an excess of erosive potential that undercuts the 'step' and progressively moves it upstream;
- general removal of bed material as a result of an excess of sediment transport capacity in the flow.

Pressures

- flow regulation such as dams can trap sediment and create a local sediment deficit in downstream flows which results in bed and bank erosion
- channelisation such as channel straightening, clearing instream obstructions, and bend cutoffs can alter the gradient of flow and increase the erosive potential
- aggregate extraction and mining can alter the bed configuration and cause bed scour
- infrastructure such as bridges, culverts and weirs can create local disruptions to flow patterns
- infestation by exotic species (eg. pigs disturbing stream beds, rubber vine killing native vegetation)
- catchment clearing can increase the rate and quantity of water entering the stream and so increase the erosion potential

Potential Causes

Hydrological & Hydraulic

- the high flow velocities associated with flood conditions generally cause the majority of bed erosion, although in some circumstances, headward erosion may occur in low flow conditions
- reduced retention and infiltration of rainfall, and more rapid runoff from catchments that have been cleared and drained results in floods that are larger than they would have been naturally, and so have greater erosive power
- the naturally sporadic nature of large flow events in the region may result in periods when there are few large flows and minimal erosion, contrasted with periods when there are a number of large flows that are close together and combine to compound erosive effects
- changes to the flow pattern that result from constrictions and obstructions (eg. culverts, weirs, bridge piers, tree trunks, snags) can produce local regions of high flow velocities that can cause severe local erosion of the bed

Geomorphological & Geotechnical

- bed erosion that occurs naturally on the outside of meander bends, can be accelerated by pressures that increase the erosive power of the stream
- changes in bed slope, resulting from channelisation or bend cutoffs for example, leads to increased sediment transport capacity and a consequent increase in erosive power

Ecological

- removal of natural vegetation from the stream channel may make the bed materials more susceptible to erosion

Possible Consequences

Geomorphological & Geotechnical

- channel deepening
- mass bank failure
- bank erosion
- downstream sedimentation

Ecological

- instream habitat degradation
- water quality degradation
- reduced conservation value

Human Use

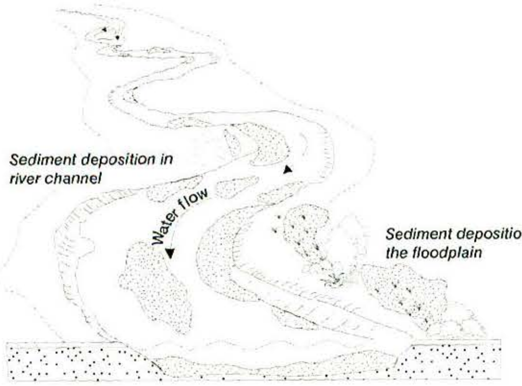
- reduced recreation value
- loss of land and infrastructure

Comments

Bed erosion can cause an overall deepening of the channel and erosion of the adjacent bank. Eroded sediment that is carried downstream may cause a reduction in flood conveyance capacity. The overall effect can be devastation of the riparian and instream habitats.

Problem Description

Sedimentation



Sediment input to stream from tributary

Description

Sedimentation refers to the deposition and accumulation of sediments within the stream channel and/or over the floodplain. Sedimentation occurs where the amount of sediment supplied to a stream exceeds the stream's ability to transport it downstream. It may also occur where flow velocities are suddenly reduced, such as when flow spills onto the floodplain. Sedimentation is a natural process which contributes to the development of geomorphic features such as deltas, meanders and natural levees. It becomes a problem when it exceeds natural rates in critical parts of the stream system.

Pressures

- flow regulation such as dams reduce downstream flows and so can reduce sediment carrying capacity
- channelisation such as channel straightening, clearing of instream obstructions, and bend cutoffs can cause erosion in the stream and subsequent sedimentation downstream
- aggregate extraction and mining can release sediments into the stream
- infrastructure such as bridges, culverts and weirs can create local disruptions to flow patterns and induce sedimentation as well as erosion
- encroachment on the stream by agriculture (eg. clearing and cultivating banks), grazing (eg. cattle disturbing the banks as they access water in the stream), and urban developments (eg. construction sites) can release sediments into the stream
- recreation activities (eg. boating can erode the banks and stir up bed sediments, camping may destroy vegetation disturb the bank)
- infestation by exotic species (eg. pigs disturbing banks, rubber vine killing native vegetation)
- catchment clearing may increase the quantity of sediment entering the stream

Potential Causes

Hydrological & Hydraulic

- a reduction in high flows in the stream because of dams can reduce the overall sediment transport ability of the stream and result in sedimentation
- obstructions to the normal flow pattern, for example, by weirs, bridges, snags etc. can produce regions of lower velocities where sedimentation will occur

Geomorphological & Geotechnical

- upstream erosion,(for example due to headcutting, bank slump, bank erosion) can provide an excess of sediment which is deposited downstream
- excess sediment may result from a major erosion episode in the past, for example from alluvial mining or a bend cutoff, that has resulted in a 'slug' of sediment which is moving downstream
- the zone of interest may be in the natural sedimentation zone of a stream that is not in equilibrium

Ecological

- establishment of instream vegetation can constrict channel flow and cause sedimentation

Possible Consequences

Geomorphological & Geotechnical

- decreased channel flow capacity
- increased overbank flow frequency
- increased risk of avulsion and anabranch development
- trend to braided characteristics

Ecological

- loss of instream habitats
- loss of riparian habitats
- reduced conservation value

Human Use

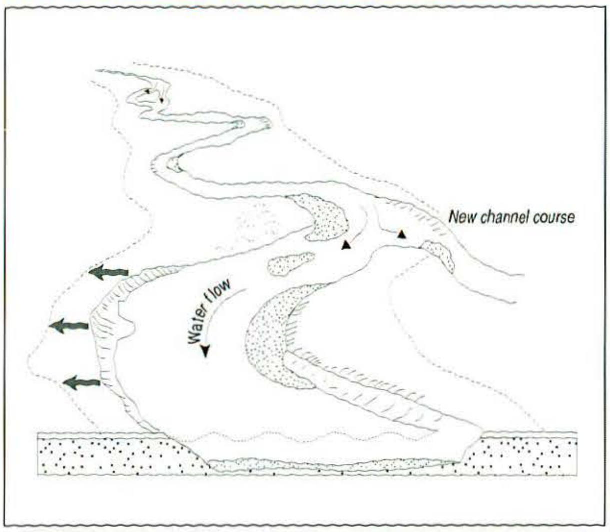
- loss of land and infrastructure
- increased flood risk
- reduced recreation value
- reduced navigability

Comments

Abnormal sedimentation is most likely to occur where there is a sudden drop in a stream's sediment transport capacity. This may arise from decreases in slope and discharge, or an increase in the sediment load. Stream sedimentation is often associated with other stream degradation processes, and contributing factors should be treated for management to be effective.

Problem Description

Channel Avulsion



Avulsion on Haughton River near Giru
(Source: Sunmap aerial photo, Haughton River 1991)

Description

Channel avulsion is the development of a new or additional stream course on a different part of the floodplain to the existing channel. It is a natural process but may be accelerated by human activities.

Pressures

- channelisation, which may increase flood capacity in one reach of the stream may cause higher water levels in other reaches and lead to avulsion
- aggregate extraction and mining causing damage and possible lowering of the banks
- encroachment on the stream by agriculture (eg. clearing and cultivating banks), grazing (eg. cattle accessing water in the stream), and urban developments (eg. stormwater discharge)
- infestation by exotic species (eg. pigs disturbing banks, rubber vine killing native vegetation)
- catchment clearing that increases the rate and quantity of water entering the stream, and increases sediment supply to the stream

Potential Causes

Hydrological & Hydraulic

- high water levels and high flow velocities associated with flood conditions generally cause the avulsion
- reduced retention and infiltration of rainfall, and more rapid runoff from catchments that have been cleared and drained results in floods that are larger and more likely to break out of the existing channel
- the naturally sporadic nature of large flow events in the region may result in periods when there are few large flows and minimal erosion, contrasted with periods when there are a number of large flows that are close together and combine to compound erosive effects
- a change in flow direction, for example caused by bridge piers or groynes, can direct the erosive forces onto the bank and increase erosion
- outflows are exacerbated by any effects that lower bank levels (eg.access track, stream crossings, cultivation, trenching for pipes or drains), or any effects which increase flood levels (eg. levees in other places, catchment drainage, urban development, obstructions in the stream)
- activities which reduce resistance to flow out of the stream and along outflow channels (eg. catchment clearing, unplanted fields, drains, roads, unvegetated banks) increase the likelihood of avulsion

Geomorphological & Geotechnical

- changes in bed slope, resulting from channelisation or bend cutoffs for example, lead to increased sediment transport capacity and a consequent increase in erosive power
- soils that become wet or saturated as a result of rainfall or flood inundation, generally lose strength and become more susceptible to overbank erosion and avulsion
- low clay content bank soils (silty to sandy) have low cohesion and are susceptible to entrainment
- unprotected and unconsolidated soils (eg. unvegetated banks, cultivated fields) are more susceptible to erosion and formation of a new channel
- piping erosion through natural levees can initiate an outbreak from the main channel
- overbank erosion can be cumulative and accelerating - one episode lowers the bank a little, the next episode occurs at a lower flood level and further lowers the bank, leading to avulsion

Ecological

- removal of vegetation on the banks and on the adjacent lands provides less resistance to water leaving the channel, and so allows higher velocities and may cause greater erosion
- lack of riparian and floodplain vegetation, which in natural systems would bind the bank and floodplain material and provide a protective barrier between the flowing water and the soil, increases the possibility of avulsion

Possible Consequences

Geomorphological & Geotechnical

- channel may adopt a new course
- anabranch development

Ecological

- loss of riparian habitat
- loss of terrestrial habitat
- degradation of previous course

Human Use

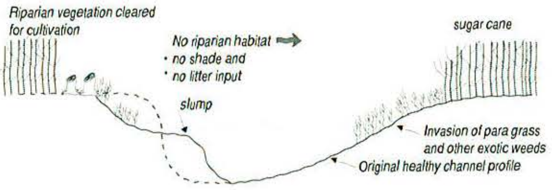
- loss of land along new course
- floodplain stripping
- damage to infrastructure
- isolation of old course and associate infrastructure

Comments

Channel avulsion is most likely to occur where overbank flows occur, such as where the channel is constricted, or where stream banks have been lowered. Though dramatic, avulsion is often the end result of slower processes that affect the balance between the stream morphology and its sediment and discharge regimes.

Problem Description

Riparian Habitat Degradation



Degraded riparian land on Proserpine River

Description

Riparian habitat degradation is a reduction in habitat diversity and habitat integrity (structure and species composition), or alterations to bank morphology. Degradation of the riparian zone may directly impact bank stability as well as habitat values.

Pressures

- flow regulation such as dams that trap sediment and create a local sediment deficit in downstream flows
- channelisation such as channel straightening, clearing instream obstructions, and bend cutoffs
- aggregate extraction and mining
- infrastructure such as bridges, culverts and weirs that can create local disruptions to flow patterns
- encroachment on the stream by agriculture (eg. clearing and cultivating banks), grazing (eg. cattle accessing water in the stream), and urban developments (eg. stormwater discharge) that directly destroy the natural system or disturb morphology and biota
- recreation activities (eg. boats generating waves, camping that destroys vegetation and disturbs the bank, plant collecting and hunting)
- infestation by exotic species (eg. pigs disturbing banks, rubber vine killing native vegetation)
- catchment clearing increases the rate and quantity of water and sediment entering the stream

Potential Causes

Hydrological & Hydraulic

- riparian habitat degradation is affected by the high water levels and high flow velocities associated with flood conditions that cause fluvial erosion
- reduced retention and infiltration of rainfall, and more rapid runoff from catchments that have been cleared and drained results in larger and more damaging floods
- changes to the flow pattern as a result of constrictions and obstructions (eg. culverts, weirs, bridge piers, tree trunks, snags) produces high flow velocities that can cause severe local bank erosion
- bed erosion that may cause steepening and undermining of banks

Geomorphological & Geotechnical

- soils that become wet or saturated as a result of rainfall or flood inundation, generally lose strength and become more susceptible to fluvial erosion and mass movements
- fluvial erosion that occurs naturally on the outer bank of meander bends, can be accelerated by pressures that increase the erosive power of the stream or reduce the erosion resistance of the bank
- changes in bed slope, resulting from channelisation or bend cutoffs for example, lead to increased sediment transport capacity and a consequent increase in erosive power

Ecological

- infestation with exotic plant species that displace native species
- infestation with feral animal species that cause physical damage (eg. disturbance by pigs), and displacement of native species (eg. predation by feral cats)

Possible Consequences

Hydrological

- increased and rapid runoff flows
- increased flooding

Geomorphological & Geotechnical

- increased fluvial erosion and mass movements
- increased overbank erosion
- disruption of natural stream processes
- increased deposition of sediment

Ecological

- severe impact on ecological processes
- loss of habitat diversity
- loss of biodiversity
- loss of continuity of habitat
- loss of connectivity between different habitats
- increase in pest species (eg. weeds, cane rats)
- exposed access to stream for fauna
- degradation of instream habitat
- reduced conservation value

Human Use

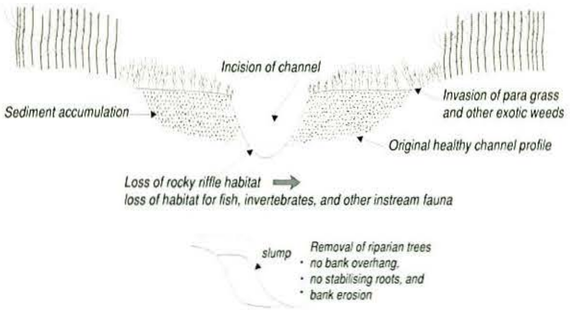
- reduced scenic and recreation values
- infrastructure and land may be lost

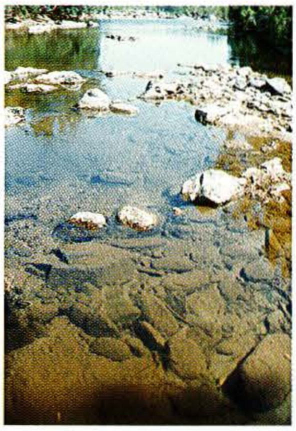
Comments

Riparian habitat degradation is widespread in most floodplain environments in north-east Queensland, and the areas where degradation is minimal require careful management to maintain their condition. Riparian habitat retention and rehabilitation should be part of integrated management of stream systems that retain riparian corridors on both banks of the streams. Riparian corridors allow the maintenance of ecological functions, and contribute substantially to bank (and land) protection, and to pest control (insects, rats, etc.)

Problem Description

Instream Habitat Degradation





Habitat degradation due to excessive sedimentation

Description

Instream habitat degradation is the reduction in habitat diversity and integrity, reduction in water quality, and alterations to bed and bank morphology. Instream habitat can be almost completely altered with devastating effects on natural plants and animals. Changes to natural habitats may promote invasion by weeds and exotic animals.

Pressures

- flow regulation by dams can trap sediment and create a local sediment deficit in downstream flows which results in bed and bank erosion; and the impoundment, diversion and release of water can significantly alter natural flow regimes
- channelisation such as channel straightening, clearing of instream obstructions, and bend cutoffs can alter stream velocities and increase erosive potential
- removal of natural vegetation from the stream channel may lead to increased erosion and subsequent downstream deposition
- aggregate extraction and mining can alter the bed configuration and produce imbalances in sediment supply and deposition
- infrastructure (such as bridges, culverts and weirs) can create local disruptions to flow patterns and induce erosion and sedimentation
- encroachment on the stream by agriculture, grazing, and urban development can affect bed morphology and habitat condition
- infestation by exotic species (eg. pigs disturbing stream beds, rubber vine killing native vegetation)
- recreation activities (eg. boats generating waves, camping that destroys vegetation and disturbs the bed and bank)
- catchment clearing can increase the rate and quantity of water entering the stream and so increase the erosion potential
- contamination from diffuse sources (eg. fertilisers and pesticides from agriculture,) and point sources (eg. sewage and stormwater discharge from urban areas) will degrade instream habitat

Potential Causes

Hydrologic & Hydraulic

- the high flow velocities associated with flood conditions can cause bed erosion and instream habitat degradation
- reduced retention and infiltration of rainfall, and more rapid runoff from catchments that have been cleared and drained, result in floods that are larger and more disruptive than they would have been naturally
- changes to the flow pattern resulting from constrictions and obstructions (eg. culverts, weirs, bridge piers, tree trunks, snags) can produce high flow velocities that can cause severe local erosion of the bed, as well as low flow areas where sedimentation may occur

Geomorphological & Geotechnical

- bed erosion and sedimentation that occurs naturally as part of meander formation, can be accelerated by pressures that alter the erosive power of the stream
- changes in bed slope, resulting from channelisation or bend cutoffs for example, lead to increased sediment transport capacity and increased erosion, with a subsequent increase in sedimentation downstream

Ecological

- loss of shade and organic input because of removal of riparian vegetation
- infestation with exotic plant and animal species can displace native species, reduce shade, reduce natural organic inputs

Possible Consequences

Hydrological

- altered flow regimes

Geomorphological & Geotechnical

- altered erosion and sedimentation rates
- alterations to natural stream processes

Ecological

- loss of habitat diversity
- loss of continuity of habitat
- loss of biodiversity
- loss of ecological function
- reduced conservation value
- invasion of exotic species

Human Use

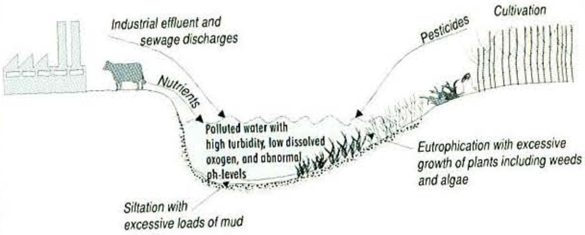
- reduced fisheries value
- reduced scenic value
- reduced recreation value
- damage to infrastructure and loss of land

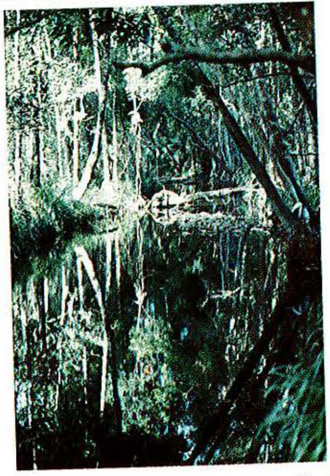
Comments

Instream habitat degradation is widespread in most floodplain environments in north-east Queensland, and the areas where degradation is minimal require careful management to maintain their condition. Instream habitat retention and rehabilitation should be part of integrated management of stream systems. The retention or re-establishment of natural flow regimes is a critical component of such rehabilitation.

Problem Description

Degraded Water Quality





Degraded water quality from sugar mill effluent

Description

Under natural conditions, streams receive contaminants from the land they drain, but in quantities that are in balance with the physical and biological processes of the stream ecosystems. Human activities can cause increased quantities and different types of contaminants to enter the stream from diffuse sources such as agricultural runoff, and from point sources such as stormwater or effluent discharge. The effects of such increased contaminant loading may not be obvious until a critical set of circumstances coincides and, for example, fish kills or algal blooms occur. In addition to damaging ecosystems, degraded water quality affects the stream utility for water supply and recreation.

Pressures

- flow regulation such as dams, diversion and release of water can significantly alter natural flow regimes and can cause poor quality water to enter the stream system
- channelisation such as channel straightening, clearing of instream obstructions, and bend cutoffs can increase erosion and turbidity
- aggregate extraction and mining can provide a significant source of suspended sediment to the stream through alteration in bed configuration and imbalances in sediment supply and deposition
- encroachment on the stream by agriculture, grazing, and urban development can produce diffuse and point source inputs of contaminants, as well as reductions in riparian vegetation that would normally filter catchment runoff
- infestation by exotic species (eg. pigs disturbing stream beds, tilapia disturbing bottom sediments)
- recreation activities (eg. boats generating waves, propellor wash which increases turbidity, oil and grease spillage from motor boats)
- contamination from diffuse sources (eg. fertilisers and pesticides from agriculture,) and point sources (eg. sewage and stormwater discharge from urban areas, effluent from industrial plants, tailwater from irrigation, minesite drainage) can increase the number and concentrations of contaminants entering the stream

Potential Causes

Hydrologic & Hydraulic

- high flow events after prolonged dry periods can flush accumulated contaminants from the catchment
- intense rainfall can mobilise catchment sediments and nutrients, and overload waste treatment facilities resulting in discharge of untreated effluent.
- water released from dams may be very poor quality (eg. anaerobic), or inappropriate for the receiving stream (eg. large temperature difference)

Geomorphological & Geotechnical

- erosion in the stream and the catchment causes increased turbidity

Ecological

- loss of riparian vegetation can reduce the filter behaviour of riparian zones and allow more contaminants into the stream
- exotic animal species (eg. tilapia, pigs) can disturb bottom sediments

Possible Consequences

Geomorphological & Geotechnical

- contamination of soils

Ecological

- change in riverine ecosystem processes
- loss of instream flora and fauna
- degradation of riparian flora
- reduced conservation value

Human Use

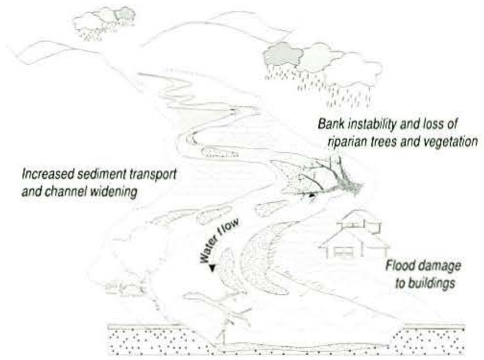
- reduced value for water supply
- reduced fish populations
- reduced recreation value

Comments

Suitable water quality is critical for all aspects of stream and riparian ecology, and for many human uses of the stream. Ecological health of the riparian and instream habitats, and the physical integrity of the catchment, is important for the maintenance of water quality. Water quality in north-east Queensland varies from pristine to highly polluted, and is impacted by swimming in small streams, agricultural chemicals in drainage and tailwater, urban drainage, sugar mills etc.

Problem Description

Altered Flood and Flow Regime



Flow regulation on Ross River, Townsville

Description

Flooding is a natural process that can become a problem when the frequency, intensity and duration of events is increased by catchment and channel modifications, or when human activities or infrastructure are disrupted or threatened. Altered flow regimes represent increased and decreased flooding, and increases and decreases in the natural non-flood flows. The major alterations are caused by flow regulation such as dams and diversions, but catchment activities such as clearing and drainage can also have significant effects. Altered flow regimes can significantly affect stream ecosystems, in extreme cases converting perennial streams to intermittent or intermittent to perennial, and eliminating flood events from the system.

Pressures

- flow regulation such as dams and diversion schemes can significantly alter the quantity and timing of flows
- channelisation, which may increase flood capacity in one reach of stream but cause higher water levels and more frequent flooding in another
- aggregate extraction may damage and lower stream banks and alter food and flow regimes
- encroachment on the stream by agriculture (eg. clearing and cultivating banks, clearing and cultivating adjacent land on the floodplain, extraction of water for irrigation), urban developments (eg. stormwater discharge, increased runoff rates)
- infestation by exotic species (eg. exotic aquatic species such as Para Grass constricting flow capacity)
- catchment clearing may increase rates and quantities of runoff and alter the rate of flood rise and fall

Potential Causes

Hydrological & Hydraulic

- flood magnitude and other characteristics are affected by catchment and stream conditions
- flooding is exacerbated by any effects that lower bank levels (eg.access track, stream crossings, cultivation, trenching for pipes or drains), or any effects which increase flood levels (eg. levees in other places, catchment drainage, urbanisation, constriction of channel flow capacity)
- impoundment of streamflow behind dams and weirs causes a general reduction in the quantity of water flowing downstream
- impoundments may have different effects on different size flow events (eg. they may have little effect on extreme floods, but may eliminate flows with a natural return period of 1 year)
- regulation can reverse natural seasonal flow patterns (eg. most water is released downstream for irrigation during the dry season when streamflow is normally low, and water is not usually released during the wet season when flows are normally high)
- catchment activities such as clearing, drainage, urban and industrial development etc. generally tend to decrease infiltration and retention and result in increased runoff, more rapid flood rise and fall, higher peak discharges and less prolonged low flows

Geomorphological & Geotechnical

- lowering or weakening of natural levees will cause flooding at lower discharges
- changes in bed slope, resulting from channelisation or bend cutoffs for example, may lead to increased downstream flooding

Ecological

- infestation of channels with exotic aquatic species may reduce flow capacity and increase or decrease flow at various locations

Possible Consequences

Geomorphological & Geotechnical

- bank and bed instability
- channel avulsion

Ecological

- riparian habitat degradation
- instream habitat degradation
- water quality degradation
- loss of biodiversity
- reduced conservation value

Human Use

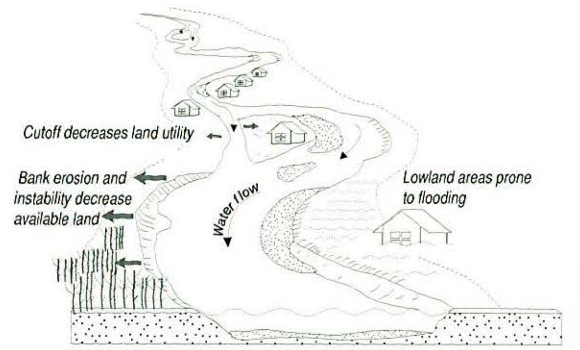
- reduced recreation value
- damage to infrastructure
- loss of utility
- economic loss
- social disruption
- loss of life
- health hazards

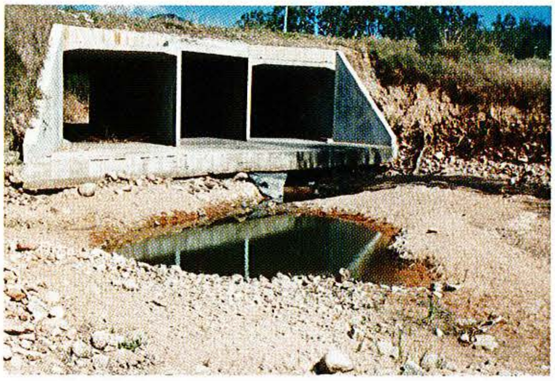
Comments

Flooding is a natural process which is necessary to replenish floodplain soils and wetlands to reset stream habitats, and to stimulate some biological activities (eg. fish spawning and migration). It becomes a problem when it is exacerbated by human activities and when human development occurs in flood-prone areas. Altered flooding and flow regimes occur in many north-east Queensland streams which have been impounded or altered in their lower reaches with levee banks and regulatory structures.

Problem Description

Loss of Land, Utility and Infrastructure





Damage to culvert, Townsville

Description

Loss of utility includes loss of agricultural, industrial or urban land, loss of availability of water due to diversion or pollution, and loss of availability of land and water used for recreation, conservation and aesthetics. It may be assessable in economic terms, or may not be readily assigned a market value. Loss or damage of infrastructure includes damage to structures and loss of useability (eg. pump station isolated by channel change).

Pressures

- flow regulation from dams can affect the downstream flow and sediment regimes, and worsen erosion and sedimentation
- channelisation such as channel straightening and clearing of instream obstructions can transfer flooding problems downstream
- aggregate extraction and mining can promote bank and bed erosion, and degrade water quality
- infrastructure such as road crossings and weirs can have many effects that erode streambanks and degrade natural habitats (eg. removal of vegetation, interruption to fish passage)
- encroachment on the stream by agriculture (eg. clearing and cultivating banks), grazing (eg. cattle disturbing banks and degrading water quality) and urban developments (eg. stormwater discharge, noise, aesthetic values)
- recreation activities (eg. boats generating waves, camping that destroys vegetation and disturbs the bank)
- infestation by exotic species (eg. pigs disturbing banks, rubber vine killing native vegetation, exotic fish displacing native species)
- catchment clearing may increase the rate and quantity of water and sediment in the stream
- contamination from diffuse sources (eg. fertilisers and pesticides from agriculture,) and point sources (eg. sewage and stormwater discharge from urban areas) will cause loss of utility

Potential Causes

Loss of utility may occur when the stream is subject to any problem that causes loss of land, damage to infrastructure, degradation of the natural form, degradation of habitat, reduced water quantity and quality, or reduction in navigability of the stream. Potential causes of loss of utility therefore encompass the potential causes of erosion, sedimentation, habitat degradation and water quality degradation.

Possible Consequences

Human Use

- diminished viability of farming operation
- disrupted transport, water supply, power supply
- loss of recreational and conservation value

Socio-economic

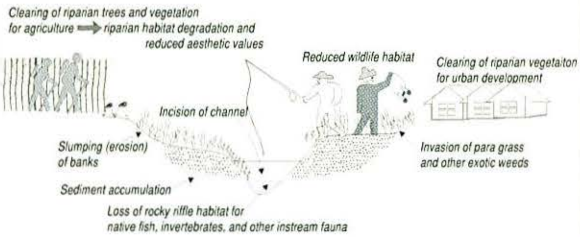
- economic loss
- costly repairs to infrastructure
- costly protection works

Comments

Loss of utility is one of the major stimuli for undertaking bank stabilisation. A great deal of the loss of utility relates to inappropriate human activity, but some is due to natural hydrological and geomorphological processes. Relevant economic, social and environmental costs and benefits should be carefully examined in any remedial program that is proposed to address loss of utility in a stream.

Problem Description

Reduced Recreation Value



Eroded bank and infestation with para grass in Ross River, Townsville

Description

Recreational values of streams are an integration of aesthetics, conservation values and navigability. Recreation uses include passive enjoyment of streams and stream banks, swimming, fishing, bird-watching, boating and water skiing. Increased recreational value for some activities (eg. power boating) may be incompatible with high recreational value for others (eg. bird watching). Power boating may have impacts on stream banks and water quality. Excessive fishing can deplete stocks and impact on conservation values. Stream bank degradation will have negative impact on many of these activities, by reducing aesthetic and conservation values, degrading fish habitat, etc.

Pressures

- flow regulation such as dams and diversions can limit the availability of water in some cases, and maintain unnaturally high flows at other times
- channelisation (such as channel straightening and clearing of instream obstructions) can degrade natural habitat (e.g fish habitat) and aesthetic values
- aggregate extraction and mining can degrade water quality
- infrastructure (such as road crossings and weirs) can have many effects that degrade both natural habitats (eg. removal of vegetation, interruption to fish passage) and aesthetic appeal (eg. noise)
- encroachment on the stream by agriculture (eg. clearing and cultivating banks), grazing (eg. cattle disturbing banks and degrading water quality) and urban developments (eg. stormwater discharge, noise, aesthetic values)
- recreation activities (eg. boats generating waves, camping that destroys vegetation and disturbs the bank)
- infestation by exotic species (eg. pigs disturbing banks, rubber vine killing native vegetation, exotic fish displacing native species)
- catchment clearing that increases the rate of delivery and quantity of water and sediment in the stream
- contamination from diffuse sources (eg. fertilisers and pesticides from agriculture,) and point sources (eg. sewage and stormwater discharge from urban areas) will reduce recreation values

Potential Causes

A reduction in recreation value may occur when the stream is subject to any problem that degrades the natural form, habitat values, or navigability of the stream. Potential causes of degradation of recreation value therefore encompass the potential causes of erosion, sedimentation, habitat degradation and water quality degradation.

Possible Consequences

Human Use

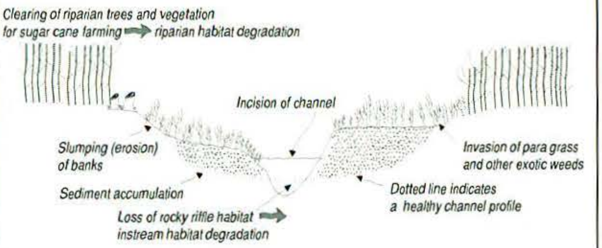
- reduced recreational value
- loss of tourism value
- abandoned recreation infrastructure
- community dissatisfaction

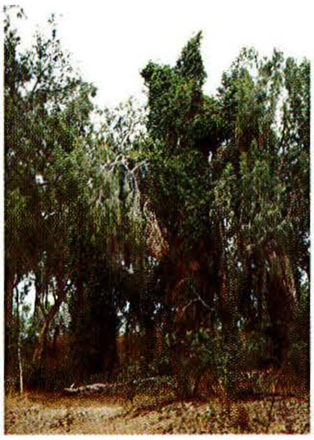
Comments

The problem is only perceived where recreation takes place, (eg. swimming holes, fishing spots, camping areas etc), although the problems (eg. habitat degradation, bank erosion) associated with reduced recreational value may be widespread.

Problem Description

Reduced Conservation Value





Reduced conservation value:
Infestation of riparian zone by rubber vine

Description

The conservation value of streams derives from their value as habitat for the flora and fauna that live in or need to pass through the stream and riparian areas, and is a function of the quality of the habitat. High quality of instream habitat depends on the maintenance of normal water quality and flow regimes, and the integrity of bed, bank and riparian vegetation. Conservation values relate not only to the immediate environment but also to the upstream and downstream environments and to the stream catchment. Problems occur when any of these important influences is modified causing changes to natural processes, habitat degradation and loss of native species. Riparian habitat is very important, especially in agricultural areas where it often represents the only remaining natural terrestrial habitat and migration route.

Pressures

- flow regulation such as dams and diversions can limit the availability of water in some cases, and maintain unnaturally high flows at other times
- channelisation such as channel straightening and clearing of instream obstructions can degrade natural habitat (e.g fish habitat) and cause problems such as sedimentation
- aggregate extraction and mining can degrade water quality
- infrastructure such as road crossings and weirs degrade natural habitats in many ways (eg. removal of vegetation, interruption to fish passage)
- encroachment on the stream by agriculture (eg. clearing and cultivating banks), grazing (eg. cattle disturbing banks and degrading water quality) and urban developments (eg. stormwater discharge, noise)
- recreation activities (eg. boats generating waves, camping that destroys vegetation and disturbs the bank)
- infestation by exotic species (eg. pigs disturbing banks, rubber vine killing native vegetation, exotic fish displacing native species, feral cats killing native animals)
- catchment clearing that increases the rate and quantity of water and sediment in the stream
- contamination from diffuse sources (eg. fertilisers and pesticides from agriculture,) and point sources (eg. sewage and stormwater discharge from urban areas) will reduce conservation values

Potential Causes

A reduction in conservation value may occur when the stream is subject to any problem that degrades the natural form, damages native vegetation, changes water quality, or results in infestation with non-native species. Potential causes of degradation of conservation value therefore encompass the potential causes of erosion, sedimentation, habitat degradation and water quality degradation.

Possible Consequences

Ecological

- loss of native plants and animals
- complete loss of species (extinction)
- create breaks in habitat connectivity

Human Use

- reduced recreational value
- loss of tourism value
- abandoned recreation infrastructure
- community dissatisfaction

Comments

Reduction of conservation values can be minimised or avoided by considering conservation objectives at all stages of problem assessment and treatment. The objectives are to avoid damaging the natural physical and biological environment; to restore natural values (eg. tree planting); and to incorporate environmentally-sensitive approaches in remediation programs.

Appendix C- Streambank Stabilisation Treatments

The full suite of stream management responses includes stream stabilisation, catchment management, stream restoration, flood mitigation or non-intervention strategies. This document focuses on stream stabilisation for rehabilitation.

The following pages provide descriptions and characteristics of streambank stabilisation treatments that are commonly used in north-east Queensland coastal streams. Summary descriptions and examples of these and other treatments used in the region are presented in Tables 1.6 to 1.10 in Chapter 1.

Table 1.5 in Chapter 1 indicates the likely suitability of individual strategies and treatments to meet stream management objectives. Treatments should be chosen to suit the local environmental conditions and site characteristics. Best Practice Guidelines for Stabilisation and Rehabilitation (Appendix D) should be followed in the planning, design and implementation of remedial programs.

Combinations of treatments will often be required to meet desired objectives for a site (eg. Rock revetment and vegetation may be used in conjunction with a pile groyne structure). Vegetation should be considered as an adjunct to all treatments.

Revegetation Strategy

- Vegetation

Alignment Training Strategy

- Rock Groyne
- Pile Groyne
- Retard
- Embayment

Bank Protection and Stabilisation Strategy

- Rock Revetment
- Rigid Revetment
- Bank Battering and Berm
- Subsurface Drainage
- Bank Chute (Surface Inflow) and Spillway (Flood Outflow)

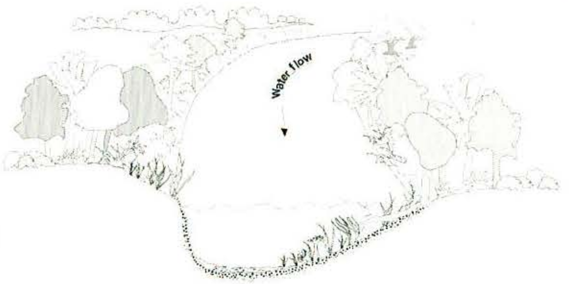
Grade Control Strategy

- Bed Chute and Drop Structure

Treatment Description

Vegetation

Revegetation Strategy



Revegetation on Cleminson Creek near Malanda

Description

Involves planting native trees, shrubs or other plants on the instream and riparian margins of the stream. Species are selected according to their ecological value in providing natural habitats and normal ecological processes, and for their ability to provide bank stabilisation and protection. Local advice is always required to ensure optimal selection of species and technique (planting, direct seeding, etc.). Advice can be obtained from Department of Environment, Department of Natural Resources, CSIRO, Wet Tropics Tree Planting Scheme, and local tree planting groups.

Application

- protect the stream bank from stream flow, waves and erosion
- reduce stream velocities through resistance to flow
- strengthen the stream bank through the plant root system
- improve habitat, conservation and aesthetic values
- rehabilitate instream and riparian systems
- improve utilitarian values

Limitations

- vulnerable to flooding when immature
- vulnerable to streamflow attack when continuity of corridor is broken
- structural contribution to stability is difficult to quantify
- relic roots may provide failure surface
- congestion of vegetation on the stream bed may inhibit streamflow and lead to flooding
- planting should be undertaken at preferred times
- availability of native plantings may be limited
- vulnerable to damage from feral and grazing animals
- requires maintenance during early stage
- incorrectly perceived as fire hazard and vermin harbourer

Design and Construction Considerations

1. Useful guides to tree planting are available from local groups, but are not included here because of the general recommendation to beware of a recipe-book approach. That is, to undertake revegetation, local advice and expertise should be sought. However, a good introduction to the process with specific suggestions relevant to the wetter parts of the study area, is Goosem and Tucker (1995).
2. Other points to note:

- consult local tree planting group for advice on suitable species etc.
- determine availability of suitable local plant stock
- design plantings to ensure correct zonation of species and structural and floristic diversity of the riparian zone
- plant to allow vegetation to establish before seasonal flooding
- high density planting necessary to maintain integrity of corridor while immature
- selective culling may be required to thin corridor as it matures
- short-term stabilisation support may be needed while plantings are immature
- temporary irrigation system may be needed for establishment of plantings (system can be used elsewhere once vegetation has matured)
- incorporate a maintenance scheme to preserve corridor continuity and to eradicate exotic vegetation
- mulch is commonly used to provide initial weed control and reduce evaporation
- if battering is necessary, incorporate surface irregularities for habitat diversity where possible
- follow suitable guidelines for planting

Combinations

Vegetation may be used alone or in combination with other treatments. Vegetation is an important adjunct to all streambank stabilisation treatments in that it enhances ecological values. Temporary structures, such as fences or revetment, mats, may be used to establish the vegetation and then be superseded once vegetation is established. A revegetation strategy also needs to consider associated treatments such as weed control and supplementary planting.

Comments

The use of exotic species is strongly discouraged. It is desirable to reinstate all structural layers from the ground layer through to the canopy. Plantings should extend beyond the high banks of streams and widths should be determined to suit stability, ecological and functional requirements. Organic or synthetic geotextile mats and hydromulch may be used in the establishment phase for erosion protection and to promote vegetation growth.

References

Goosem S. and Tucker N.I.J. 1995, *Repairing the Rainforest: Theory and Practice of Rainforest Re-establishment in North Queensland's Wet Tropics*, Wet Tropics Management Authority, Cairns 72p.

Treatment Characteristics

Vegetation

Revegetation Strategy

Physical

Hydrological & Hydraulic

- increases flow resistance and may redirect flow to new alignment
- reduces local flow velocities and inhibits local erosion
- high velocities and turbulence may occur adjacent to vegetation
- vulnerable to damage from high flow velocities when immature
- roots can increase soil permeability
- filters sediment and nutrient runoff from riparian lands

Geomorphological & Geotechnical

- improves bank stability by protecting and consolidating bank material
- can reduce sediment supply to stream from banks
- can trap sediment and improve balance between erosion and accretion
- improves resistance to overbank erosion through root mats and restriction of flood flow

Ecological

Instream

- increases or restores habitat diversity
- provides shelter from stream flow
- collects sediment and debris, enhancing habitat diversity
- provides a source of snags (major habitat, spawning sites) and organic matter (vital in food chain)
- revegetation with native species will reduce weed infestation (eg. by para grass)
- provision of shade reduces temperature fluctuations and limits algal growth
- retains vital land/water interface
- may be used alone where appropriate or in conjunction with 'harder' techniques to improve their ecological performance

Riparian

- native revegetation of bank provides habitat diversity, rehabilitation of bank and reinstatement of corridor continuity
- riparian habitat vital for terrestrial and semi-aquatic species (eg. emerging insects, fish-eating birds); drought refuge for terrestrial species, and only available habitat for many species in an agricultural or urban landscape
- native revegetation helps prevent establishment of weeds both on the bank and in the stream
- provides shade (reduces temperature range and growth of weeds) and organic input to food chain
- filters overbank inputs to stream
- fallen trees provide important habitat on the bank and instream

Socio-economic

Social

- has intrinsic conservation value
- improves natural scenic values
- facilitates nature-based recreation
- can be implemented with 'hands on' community involvement

Economic

- requires active maintenance (irrigation, weed control) in early stages
- minimal investigation and design costs
- implementation costs will vary depending on labour costs
- widespread revegetation will reduce other stream management problems
- widespread revegetation will improve recreational and commercial fisheries
- labour intensive implementation provides opportunities for local job creation
- not yet possible to calculate expected performance in terms of Factor of Safety etc.

Treatment Description

Rock Groyne

Alignment Training Strategy

Rock Groynes on the Haughton River near Giru

Description

Rock groynes are impermeable alignment training structures that project from the bank into the stream, obstructing the streamflow adjacent to the bank. They are relatively short structures that are typically used in the low flow channel on the outside of a bend where deeper water abuts an eroding bank. The principal variations to rock groynes are gabions, reinforced concrete walls and randomly-stacked concrete blocks

Application

- direct streamflow through new alignment and inhibit flow adjacent to the bank
- divert strong currents away from an eroding bank
- control stream width, induce channel deepening or constriction
- protect infrastructure such as bridges
- protect eroded bank without major stream re-alignment
- improve navigability of channel
- encourage deposition on the outside of a bend and reclamation of the bank
- facilitate physical & ecological rehabilitation of bank

Limitations

- may induce local scour downstream and at the outer end of the groyne
- settlement and dislodgment of rock may occur over time
- difficult to revegetate structure
- disturbance to habitat during construction
- availability of appropriate construction material
- natural channel migration may be modified leading to, for example, increased erosion elsewhere and/or cut-offs over the longer-term

Design and Construction Considerations

1. Design information is included in Standing Committee on Rivers and Catchments (1991) (Chapter 8).
2. Other points to note:

- provide for reversal of stream currents in estuarine areas
- top of groyne should be above low flow level but should be below design flood level and the top of the bank (to prevent breakout)
- abutment height is normally higher than the instream end
- protect groyne toe and abutment against erosion
- disruption to stream bank habitat may be minimised by construction from barges or from the stream bed
- specify revegetation of bank and riparian margin using native species

Combinations

Revegetation strategies and bank protection works such as rock revetment are commonly integrated with alignment training structures such as rock groynes. Rock groynes constructed adjacent to the bank may be combined with pile groynes that are placed in the deeper water farther from the bank.

Comments

Rock groynes have been used traditionally for bank protection and alignment training, particularly in meandering streams. These impermeable groynes are more susceptible to scour damage than are permeable pile groynes. They are also less suited to very deep water situations than pile groynes because of material quantities required and construction limitations. Some sediment deposition may be achieved, and rock groynes provide some positive ecological effects by protecting banks and riparian vegetation, and by introducing habitat diversity.

References

Standing Committee on Rivers and Catchments 1991, *Guidelines for Stabilising Waterways*, prepared by the Working Group on Waterway Management, Victoria.

Treatment Characteristics

Rock Groyne

Alignment Training Strategy

Physical

Hydrological & Hydraulic

- inhibits streamflow through groyne field
- directs streamflow to new alignment
- reduces flow velocity adjacent to the outer bank
- increases flow velocity through new alignment
- high velocities and turbulence are likely immediately downstream and at the end of the groynes
- may increase local water level and increase risk of flooding
- increases streamflow loading with trapped debris

Geomorphological & Geotechnical

- reduces erosive flows against bank
- decrease effective channel width locally, at least temporarily
- may modify natural meander migration
- may modify channel geometry (width, depth slope), at least temporarily
- may contribute to bed erosion adjacent to new alignment
- may contribute to bank erosion at abutments during overtopping

Ecological

Instream

- introduces alien habitat, but -
- may increase habitat diversity locally (backwaters, hard substrates, holes between rocks, etc.)
- provides shelter from main flow (favours some species)
- may collect sediment and debris (increasing habitat diversity), but may cause stagnation
- may facilitate instream revegetation in shallower parts but may encourage growth of aquatic weeds
- chemicals may leach from rock
- revegetation of banks provides riparian cover and organic input between groynes
- retains vital land/water interface
- provides basking and perching sites

Riparian

- revegetation of bank with native species provides habitat diversity and allows rehabilitation of bank and corridor continuity
- may reduce natural riparian habitat
- without revegetation, riparian community becomes dominated by weeds
- maintains access for animals to stream, bank and floodplain habitats

Socio-economic

Social

- moderate to high reduction in scenic values
- can provide increased recreational fishing opportunities
- can help maintain navigability

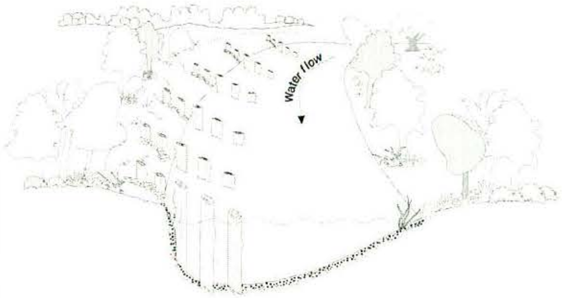
Economic

- moderate to high investigation and design costs
- high construction costs
- majority of construction by heavy machinery

Treatment Description

Pile Groyne

Alignment Training Strategy



Groynes on the Mulgrave River near Gordonvale

Description

Pile groynes are permeable alignment training structures that project from the bank into the stream, increasing flow resistance and directing flow away from the bank. They are relatively short structures that are typically used in the low flow channel on the outside of a bend where deeper water abuts an eroding bank.
The principal variations to pile groynes are timber piles, steel piles and concrete piles.

Application

- direct streamflow through new alignment and inhibit flow adjacent to the bank
- divert strong currents away from an eroding bank
- reduce erosion potential of high flows
- control stream width, induce channel deepening or constriction
- protect infrastructure such as bridges
- improve navigability of channel
- encourage deposition on the outside of a bend and reclamation of the bank
- facilitate physical and ecological rehabilitation of bank

Limitations

- local scour may occur around base of piles and at abutments
- disturbance to habitat during construction
- debris may lodge on piles during flooding, leading to bed and bank erosion

Design and Construction Considerations

1. No detailed design and construction information is available; however, Dyer et al. (1995) provide some information on performance and guidance on design. General information on design of groynes is included in Standing Committee on Rivers and Catchments (1991) (Chapter 8).
2. Other points to note:

- provide for reversal of stream currents in estuarine areas
- specify non-toxic timber that is rot-resistant
- consider bed scour when specifying pile embedment depth
- top of pile should remain above low flow level but extension above water should be minimised to prevent timber piles from drying
- pile height should be below design flood level and the top of the bank (to prevent breakout)
- abutment height is normally higher than the instream end
- two rows of close and alternately spaced piles are commonly used
- a downstream inclination of piles is commonly used to facilitate debris shedding
- protect groyne toe and abutment against erosion
- disruption to stream bank habitat may be minimised by construction from barges or from the stream bed
- specify revegetation of bank and riparian margin using native species

Combinations

Revegetation strategies and bank protection such as rock revetment are commonly integrated with alignment training structures such as pile groynes. Pile groynes could be considered in deep water sections in conjunction with rock groynes, placed in shallower water adjacent to the bank.

Comments

Unlike rock groynes, pile groynes continue to function with limited scouring of the stream bed. Rock can be placed around the base of piles to prevent scouring and reduce pile deflection. Pile groynes can be constructed in deep water and are suitable for use in sites with existing scour holes.

Pile groynes provide positive ecological effects by protecting banks and riparian vegetation, and by introducing habitat diversity. Construction in timber minimises the ecological impact on the stream.

References

Dyer, B.G., Western, A.W. & Grayson, R.B. 1995, *Hydraulic Characteristics of Retards*, report prepared for Centre for Environmental Applied Hydrology, University of Melbourne.

Standing Committee on Rivers and Catchments 1991, *Guidelines for Stabilising Waterways*, prepared by the Working Group on Waterway Management, Victoria.

Treatment Characteristics

Pile Groyne

Alignment Training Strategy

Physical

Hydrological & Hydraulic

- inhibits streamflow through groyne field
- directs streamflow to new alignment
- reduces flow velocity adjacent to the outer bank
- increases flow velocity through new alignment
- high velocities are likely around base of piles and at abutments
- may increase local water level and increase risk of flooding
- streamflow loading will increase with trapped debris

Geomorphological & Geotechnical

- reduces erosive flows against bank
- decrease effective channel width, at least temporarily
- may modify natural meander migration
- may modify channel geometry (width, depth slope), at least temporarily
- may contribute to bed erosion adjacent to new alignment
- may contribute to bank erosion at abutments during overbank flows

Ecological

Instream

- introduces alien habitat, but -
- may increase habitat diversity locally (slow flow, eddies, backwaters)
- provides shelter from main flow (favours some species)
- may collect sediment and debris, increasing habitat diversity
- may facilitate instream revegetation in shallower parts
- but may encourage growth of aquatic weeds
- revegetation of banks provides riparian cover and organic input between groynes
- retains vital land/water interface
- retains fish passage along the stream
- treated timber piles may leach toxic chemicals
- provides basking and perching sites

Riparian

- revegetation of bank with native species provides habitat diversity and allows rehabilitation of bank and corridor continuity
- without revegetation, riparian community becomes dominated by weeds
- maintains access for animals to stream, bank and floodplain habitats

Socio-economic

Social

- neutral effect on scenic values if construction impacts are minimised
- can help maintain navigability
- can provide increased recreational fishing opportunities

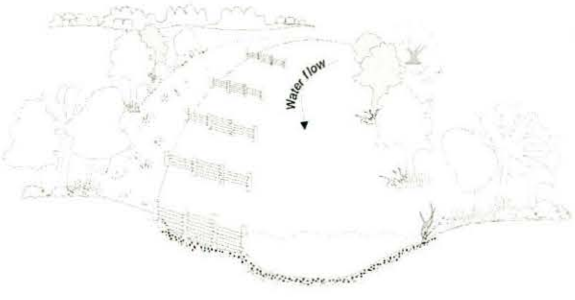
Economic

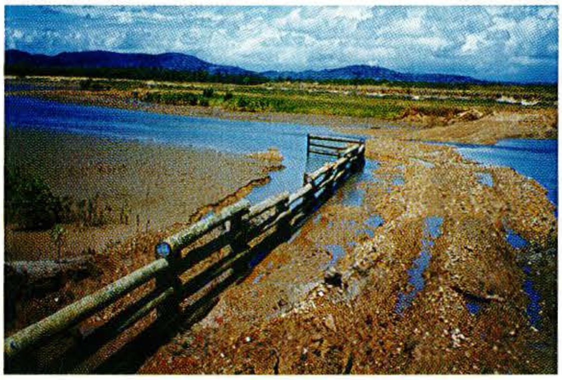
- moderate to high investigation and design costs
- high construction costs
- possible to use recycled materials eg. old jetty piles
- operational life less than for rock groynes as materials subject to biological degradation
- majority of construction by heavy machinery
- improved riparian and instream habitat will improve fisheries

Treatment Description

Retard

Alignment Training Strategy





Timber pile and rail retards on the O'Connell River near Proserpine

Description

Retards are permeable alignment training structures that project from the streambank, increasing flow resistance. They are long and low pile and rail structures. Retards are typically used on the outside of a bend in shallow stream settings and are often constructed on low terraces. Vegetation should be established between retards to encourage sediment deposition.

The principal variations for retards are timber pile and rails, steel piles and timber rails.

Application

- encourage deposition on the outside of a bend and reclamation of the bank
- direct streamflow through new alignment and inhibit flow adjacent to the bank
- divert low currents away from an eroding bank
- reduce local erosion potential of high flows
- protect infrastructure such as bridges
- control stream width, induce channel deepening or constriction
- improve navigability of channel
  facilitate physical and ecological rehabilitation of bend

Limitations

- local scour may occur around base of retards and at abutments
- debris may lodge on piles during flooding, leading to bed and bank erosion

Design and Construction Considerations

1. Design information is included in Standing Committee on Rivers and Catchments (1991) (Chapter 8). Information on performance and guidance on design is available in Dyer et al. (1995).
2. Other points to note:

- retards typically extend 1-2 metres above bed level
- a terrace may be constructed to provide a dry, stable workplace for construction
- allow for bed/terrace erosion by installing cross-members below bed/terrace level
- protect abutment against erosion by using rock and embed retard into bank
- use non-toxic timber that is rot-resistant
- retards are sometimes provided as temporary structures to facilitate revegetation of the stream
- specify native revegetation between retards (encourages sediment deposition)
- specify revegetation of bank and riparian margin using native species

Combinations

Revegetation should be used with retards. Bank protection such as rock revetment is commonly integrated with retards.

Comments

Vegetation within the retard field is important to reclaim and maintain a new alignment.

Retards provide positive ecological effects by protecting banks and riparian vegetation, introducing habitat diversity, and facilitating re-establishment of native vegetation.

References

Standing Committee on Rivers and Catchments 1991, *Guidelines for Stabilising Waterways,* prepared by the Working Group on Waterway Management, Victoria.

Dyer, B.G., Western, A.W. & Grayson, R.B. 1995, *Hydraulic Characteristics of Retards,* report prepared for Centre for Environmental Applied Hydrology, University of Melbourne.

Treatment Characteristics

Retard

Alignment Training Strategy

Physical

Hydrological & Hydraulic

- inhibits streamflow through retard field
- directs streamflow to new alignment
- reduces flow velocity through retard field at low flows
- increases flow velocity through new alignment at low flows
- high velocities are likely around base of retards and at abutments
- revegetation in retard field will increase flow resistance and reduce likelihood of erosion
- streamflow loading will increase with trapped debris

Geomorphological & Geotechnical

- reduces erosive flows against bed and bank at low flows
- re-alignment decreases effective channel width, at least temporarily
- may modify natural meander migration
- may modify channel geometry (width, depth slope), at least temporarily
- may contribute to bed erosion adjacent to new alignment
- local scour may occur around base and abutment of retards
- encourages deposition of coarse sediments between retards
- encourages deposition of fine sediments when retards are used with vegetation and/or constructed on berms and terraces
- deposited sediment stabilised through revegetation
- may be used to encourage pool and riffle sequence

Ecological

Instream

- introduces alien habitat, but -
- may increase habitat diversity locally (backwaters, etc.)
- provides shelter from main flow (favours some species)
- may collect sediment and debris (increases habitat diversity)
- facilitates instream revegetation
- but may encourage growth of aquatic weeds
- revegetation provides cover and organic input between retards
- retains vital land/water interface
- retains fish passage along the stream
- chemicals may leach from treated timber
- provides basking and perching sites

Riparian

- possibility of substantial reclamation and revegetation of bank, providing habitat diversity and allows rehabilitation of bank and corridor continuity
- without revegetation, riparian community becomes dominated by weeds
- maintains access for animals to stream, bank and floodplain habitats

Socio-economic

Social

- moderate reduction in scenic values
- can help maintain navigability

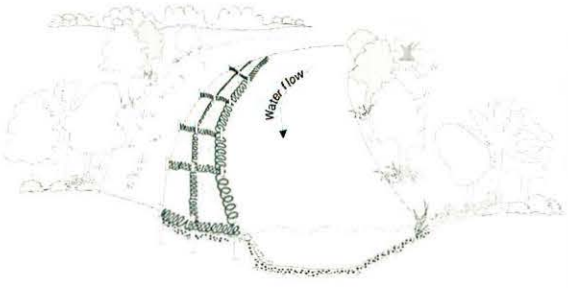
Economic

- moderate to high investigation and design costs
- moderate to high construction costs
- opportunities to use recycled materials
- timber structures subject to fire damage and biological degradation
- labour-intensive construction provides opportunities for local job creation

Treatment Description

Embayment

Alignment Training Strategy



Steel pile and wire mesh embayments on Cattle Creek near Mackay

Description

Embayments are permeable alignment training structures that are used to reclaim part of an eroded stream by obstructing stream flow adjacent to the bank. They are long and low structures usually comprised of fences placed in a grid pattern. Embayments are typically used on the outside of a bend in shallow stream settings and are often constructed on low terraces. Vegetation should be established within the embayment grid to encourage sediment deposition.

The principal variations for embayments are: mesh fences, timber fences, jacks.

Application

- encourage deposition on the outside of a bend and reclamation of the bank
- direct streamflow through new alignment and inhibit flow adjacent to the bank
- divert low flow away from eroding bed and bank
- reduce local erosion potential of high flows
- protect infrastructure such as bridges
- control stream width, induce channel deepening or constriction
- improve navigability of channel
- facilitate physical and ecological rehabilitation of bend

Limitations

- lack of performance information in coarse and fine bed streams
- local scour may occur under embayment fences and at abutments
- debris may lodge on embayment fences during flooding, leading to bed and bank erosion, and damage to the fences
- disturbance to habitat during construction
- appears unnatural without revegetation

Design and Construction Considerations

1. No detailed design and construction information is available; however, Rankine (1982) provides guidance on design.
2. Other points to note:

- terraces may be constructed to provide a dry, stable workplace for construction
- rock revetment may be placed along bank abutment and channel extent of new alignment to protect against erosion
- embayments are sometimes provided as temporary structures to facilitate revegetation of the stream
- durability of structure is reduced by abrasion and corrosion
- specify native revegetation within embayment grid (encourages sediment deposition)
- specify revegetation of bank and riparian margin using native species

Combinations

Revegetation should be used with embayments. Bank protection such as rock revetment is commonly integrated with embayments.

Comments

Little design and performance information is available for successful implementation.

Vegetation within the embayment field is important to reclaim and maintain a new alignment.

Embayments provide some positive ecological effects by protecting banks and riparian vegetation, introducing habitat diversity, and facilitating re-establishment of native vegetation.

References

Rankin, D. 1982, Stabilising stream channels by river training and interaction with the environment, *Civil Engineering Transactions 1982*, pp. 135-142.

Treatment Characteristics

Embayment
Alignment Training Strategy

Physical

Hydrological & Hydraulic

- inhibits streamflow and reduces flow velocity through embayment field at low flow
- directs streamflow to new alignment
- increases flow velocity through new alignment at low flows
- high velocities are possible around piles, under mesh fences and at abutments
- revegetation in embayment field will increase flow resistance and reduce likelihood of erosion
- mesh fences may trap debris and be damaged in flooding

Geomorphological & Geotechnical

- reduces erosive flows against bank at low flows
- re-alignment decreases effective channel width, at least temporarily
- may modify natural meander migration
- may modify channel geometry (width, depth, slope), at least temporarily
- may contribute to bed erosion adjacent to new alignment
- local scour may occur around base and abutment of embayment fences
- encourages deposition of coarse sediments between embayments
- encourages deposition of fine sediments when embayments are used with vegetation
- deposited sediment stabilised through revegetation

Ecological

Instream

- introduces alien habitat, but -
- may increase habitat diversity locally (backwaters, etc.)
- provides shelter from main flow (favours some species)
- may collect sediment and debris (increases habitat diversity)
- facilitates instream revegetation
- but may encourage growth of aquatic weeds
- revegetation provides riparian cover and organic input
- restricts fish passage along the stream

Riparian

- native revegetation of bank provides habitat diversity and allows rehabilitation of bank and corridor continuity
- without revegetation, riparian community becomes dominated by weeds
- restricts access for animals to stream, bank and floodplain habitats

Socio-economic

Social

- moderate to high reduction in scenic values
- can help maintain navigability

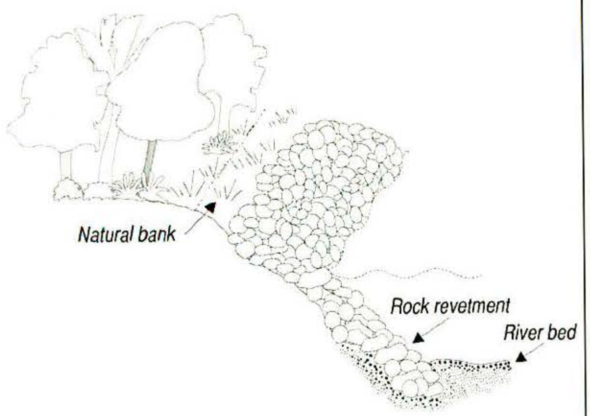
Economic

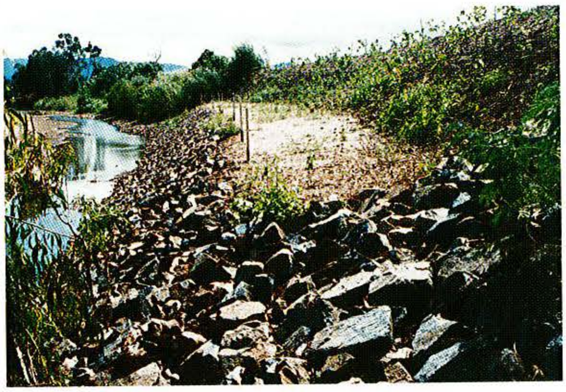
- relatively low investigation and design costs
- moderate to high construction costs
- access for irrigation equipment may be restricted
- moderately labour-intensive construction provides opportunities for local job creation

Treatment Description

Rock Revetment

Bank Protection and Stabilisation Strategy





Rock revetment and revegetation on Herbert River near Ingham

Description

Rock revetments are flexible and permeable layers of rock that armour the stream bank against fluvial erosion and stabilise against slumping. Revetments typically armour the toe of the bank but can also extend to the upper bank.

The principal variations to rock revetments are: rock gabions, crib walls, stone pitching, dumped rock. Other material used for revetment construction include tied logs, grass reinforced with geotextile mats.

Application

- protect stream bank against fluvial erosion
- limit undercutting of banks
- restrain meander migration
- surcharge bank toe against mass movements
- protect infrastructure such as bridges and buildings

Limitations

- local scour may occur at toe and downstream end of structure
- may develop unstable alignments due to flow redirection
- commonly breaks continuity of riparian vegetation corridor
- alters terrestrial / aquatic interface
- may cause disturbance to habitat during construction and maintenance
- difficult to revegetate
- appears unnatural unless revegetated

Design and Construction Considerations

1. Design information is included in Standing Committee on Rivers and Catchments (1991) (Chapter 6).
2. Other points to note:

- may be practical to protect only the lower section of the bank
- avoid blocking subsurface water drainage through the bank
- provide for revegetation of structure where possible
- avoid using rock with adverse chemical characteristics that affect water quality
- use rock with good durability
- disruption to stream bank habitat may be minimised by construction from barges or from the stream bed
- specify revegetation of bank and riparian margin using native species

Combinations

Vegetation is commonly used in conjunction with bank protection and stabilisation treatments such as rock revetments and, with careful design, may be incorporated within the rock, gabion or other revetment construction. Subsurface drainage and bank battering and berms are commonly combined with rock revetments.

Comments

Rock revetment has been used traditionally for bank protection and stabilisation, sometimes with adverse effects on stream morphology in adjoining reaches.

Rock revetment has low ecological value, but is improved by combination with revegetation of the upper bank and use of large rocks at the toe. It is unlikely to have significant adverse effect on instream and riparian habitat when used in short segments.

References

Standing Committee on Rivers and Catchments 1991, *Guidelines for Stabilising Waterways*, prepared by the Working Group on Waterway Management, Victoria.

Treatment Characteristics

Rock Revetment

Bank Protection and Stabilisation Strategy

Physical

Hydrological & Hydraulic

- may streamline flow along streambank
- may alter streamflow alignment downstream
- increases flow velocity adjacent to revetment
- high velocities and turbulence are possible at toe and downstream end of revetment
- may impede subsurface water drainage

Geomorphological & Geotechnical

- protects bank by armouring with coarse materials
- fixes channel planform and position
- modifies channel migration
- may modify channel depth and slope, at least temporarily
- bed erosion may occur adjacent to revetment, with scouring and undercutting possible
- transitions to untreated bank may be vulnerable to scour and undercutting
- nearby banks are vulnerable to erosion by deflected flow
- eroded sediment may be deposited and cause aggradation downstream
- revetment materials may be mobilised and exacerbate erosion through abrasion and current deflection during high streamflows

Ecological

Instream

- introduces alien habitat but increases habitat diversity locally (hard substrates, holes between rocks etc.)
- simplifies bank morphology and causes loss of shallows and underbank habitat
- minimises growth of aquatic plants
- existing vegetation commonly removed during construction
- provides barrier to vital land/water interface
- retains fish passage along the stream
- chemicals may leach from rock

Riparian

- degrades habitat diversity
- may allow for rehabilitation of upper bank if rock restricted to lower bank
- may break longitudinal wildlife corridor
- eliminates cover and shade to lower bank
- limits normal organic input to stream
- native revegetation of upper bank provides habitat diversity and allows rehabilitation of bank and corridor continuity
- restricts access for animals to stream, bank and floodplain habitats
- revegetation amongst rocks possible with careful design
- without revegetation, riparian community becomes dominated by weeds

Socio-economic

Social

- large reduction in scenic values
- can provide increased recreational fishing opportunities compared with naturally vegetated bank

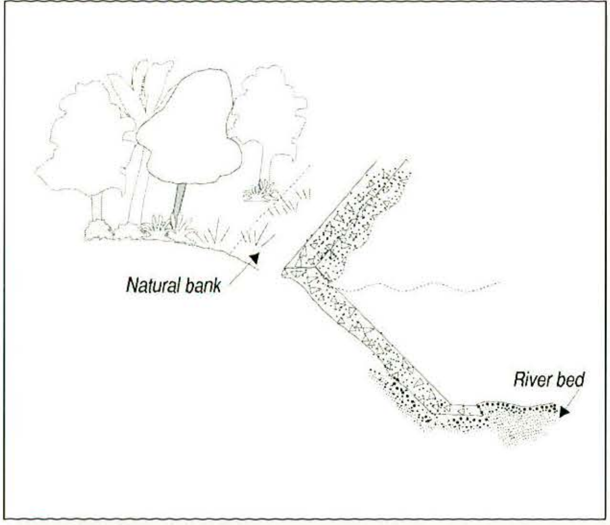
Economic

- low to moderate investigation and design costs
- high construction costs
- majority of construction by heavy machinery

Treatment Description

Rigid Revetment

Bank Protection and Stabilisation Strategy



Concrete revetment in tidal area of Ross Creek, Townsville

Description

Rigid revetments are inflexible and impermeable walls or layers that armour the stream bank against fluvial erosion and stabilise against slumping. Revetments typically armour the toe of the bank but can also extend to the upper bank. Rigid revetments are commonly used to protect infrastructure and in estuaries where navigation is common.

The principal variations for rigid revetment are reinforced concrete retaining walls, interlocking sheet piling, grouted rock layer, pile and panel walls

Application

- protect stream bank against fluvial erosion
- limit undercutting of banks
- restrain meander migration
- increase resistance of stream bank to slump failure
- surcharge bank toe against mass movements
- protect infrastructure such as bridges and buildings
- provide recreational access (boat ramps)

Limitations

- local scour may occur at toe and downstream end of structure
- unstable alignments may develop due to flow redirection
- may cause acceleration of flow and increased velocities
- rigidity makes structure vulnerable to mass movements
- inhibits subsurface water seepage from the bank, which may destabilise the structure
- tree roots may destabilise the structure
- commonly breaks continuity of riparian vegetation corridor
- alters terrestrial / aquatic interface and destroys habitat values
- disturbs habitat during construction and operation
- difficult to revegetate
- appears starkly unnatural

Design and Construction Considerations

1. General design information for rigid revetments is included in Hemphill, R.W. & Bramley, M.E. (1989). Most structural and geotechnical engineering textbooks provide design guidance for retaining walls.
2. Other points to note:

- may be practical to protect only the lower section of the bank
- avoid blocking subsurface water drainage through the bank
- disruption to stream bank habitat may be minimised by construction from barges or from the stream bed
- specify revegetation of bank and riparian margin using native species

Combinations

Vegetation is sometimes used in conjunction with bank protection and stabilisation treatments such as rigid revetments. Subsurface drainage and bank battering and berms are commonly combined with rigid revetments.

Comments

Rigid revetment has been used traditionally for bank protection and stabilisation, particularly in urban and estuarine areas.

Rigid revetment has no ecological value except where protecting terrestrial habitat. Ecological value is improved by revegetation of the upper bank. Use of rigid revetment should be limited to purposes such as infrastructure protection.

References

Hemphill, R.W. & Bramley, M.E. 1989, *Protection of River and Canal Banks, A Guide to Selection and Design*, Water Engineering Report for the Construction Industry Research and Information Association, Butterworths, London, 200p.

Treatment Characteristics

Rigid Revetment

Bank Protection and Stabilisation Strategy

Physical

Hydrological & Hydraulic

- streamlines flow along streambank
- may alter streamflow alignment downstream
- increases flow velocity adjacent to revetment and downstream
- high velocities and turbulence are likely at toe and downstream end of revetment
- likely to impede subsurface water drainage

Geomorphological & Geotechnical

- protects bank by armouring with rigid material
- fixes channel planform and position
- restricts channel migration
- may modify channel depth and slope, at least temporarily
- bed erosion may occur adjacent to revetment, with scouring and undercutting possible
- transitions to untreated bank may be vulnerable to scour and undercutting
- nearby banks are vulnerable to erosion by deflected flow
- eroded sediment may be deposited and cause aggradation downstream

Ecological

Instream

- drastically reduces habitat diversity (eliminates normal bank habitat)
- eliminates vegetation
- provides barrier to vital land/water interface
- retains fish passage along the stream

Riparian

- drastically reduces habitat diversity; breaks longitudinal habitat continuity, but
- may allow revegetation and rehabilitation of upper bank, and longitudinal habitat continuity, if rigid revetment restricted to lower bank
- without revegetation upper bank becomes dominated by weeds
- removes shade and organic input to stream
- restricts access for animals to stream, bank and floodplain habitats

Socio-economic

Social

- high impact on natural scenic values, but may be appropriate in highly developed settings eg. boardwalks, marinas etc
- can provide increased recreational fishing opportunities compared with naturally vegetated bank
- can inhibit local access to stream

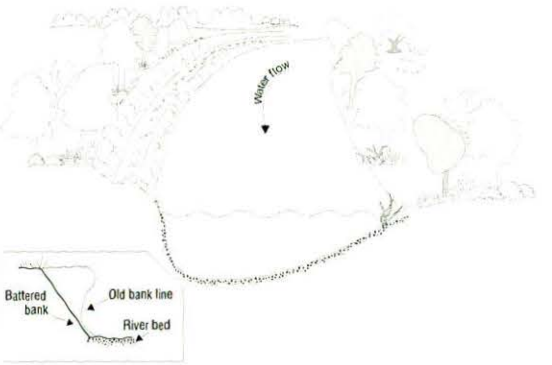
Economic

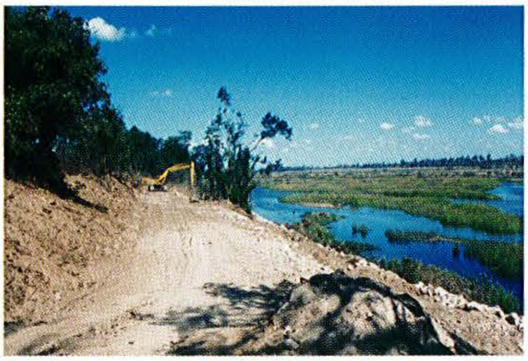
- high investigation and design costs
- high construction costs
- usually labour-intensive and may provide opportunities for local job creation

Treatment Description

Bank Battering & Berm

Bank Protection and Stabilisation Strategy





Battering and berm for revetment construction on Burdekin River

Description

Bank battering and berms involve reshaping the bank to improve bank stability and to provide construction and maintenance access. This treatment is commonly used where scouring or slumping has occurred, and as a preparation for placement of other stabilisation works such as rock revetment, subsurface drainage and vegetation.

The principal variations for bank battering and berms are single or multiple berms, and uniform or irregular battering.

Application

- provide stable bank configuration
- reduce surcharge loading on streambank
- provide construction and maintenance access
- rejuvenate a degraded riparian zone

Limitations

- unprotected bank vulnerable to erosion
- may streamline flow and cause downstream erosion
- may reduce existing ecological values
- commonly breaks continuity of riparian vegetation
- uniform profile lacks habitat diversity
- appears unnatural

Design and Construction Considerations

1. Most geotechnical engineering textbooks provide design guidance for establishing stable slopes for bank battering and berms.
2. Other points to note:

- choose bank and berm configuration to suit slope stability, soil properties and subsurface water conditions
- provide surface drainage and disposal to prevent erosion
- provide access to berm where possible
- avoid disturbing instream and riparian habitats during construction
- preserve native vegetation where possible
- incorporate surface irregularities for habitat diversity where possible
- specify revegetation of bank and riparian margin using native species

Combinations

Vegetation is commonly used in conjunction with bank protection and stabilisation treatments such as bank battering and berms. Battering and berms are commonly combined with rock revetments and subsurface drainage.

Comments

Battering and berms have been used traditionally for bank protection and stabilisation.

This treatment is, in itself, ecologically destructive but when used to restore vegetation, does allow an improvement in ecological values.

Battering and berms are likely to erode and fail unless structural or vegetative stabilisation is implemented.

Organic or synthetic geotextile mats and hydromulch may be used in the establishment phase for erosion protection and to promote vegetation growth.

Treatment Characteristics

Bank Battering & Berm

Bank Protection and Stabilisation Strategy

Physical

Hydrological & Hydraulic

- streamlines flow along streambank
- local high velocities and turbulence may erode bank

Geomorphological & Geotechnical

- stabilise bank by reducing overall bank steepness and susceptibility to slumping
- fixes channel planform and position, at least temporarily
- vulnerable to undercutting and failure if not constructed properly, or if flow conditions change
- weakened by rill, gully or pipe development on exposed sloping face, especially in streams with seasonally varied flows
- vulnerable to stock disturbance and surface abrasion due to raindrop impact and waves
- sediment eroded from battered banks and berms may cause aggradation downstream
- readily stabilised with revegetation

Ecological

Instream

- reduces habitat diversity
- simplifies bank morphology and causes loss of shallows and underbank habitat
- limits cover and shade
- revegetation of banks provides riparian cover and organic input
- retains land/water interface, although severely altered
- retains fish passage along the stream

Riparian

- degrades habitat diversity
- may break longitudinal wildlife corridor
- eliminates cover and shade to lower bank
- limits normal organic input to stream
- native revegetation of bank provides habitat diversity and allows rehabilitation of bank and corridor continuity
- without revegetation, riparian community becomes dominated by weeds
- limited protection for vegetation during major flooding

Socio-economic

Social

- high reduction in scenic values if not appropriately revegetated

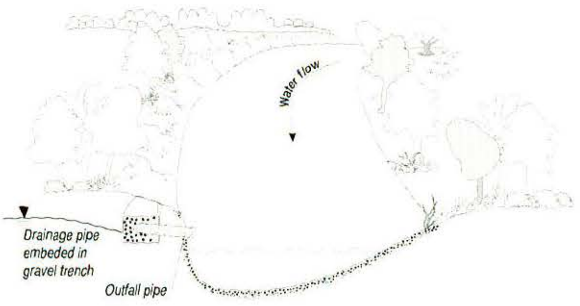
Economic

- low investigation and design costs
- low to moderate construction costs
- continued maintenance required unless surface protection and stabilisation provided
- construction primarily using heavy machinery

Treatment Description

Subsurface Drainage

Bank Protection and Stabilisation Strategy



Perforated drainage pipe for lateral subsurface drainage on Herbert River Anabranch

Description

Subsurface drainage incorporates perforated pipes or trenches installed in the stream bank to lower the water table, reduce subsurface pressures and reduce the potential for slumping failures. Subsurface drainage is usually installed in the lower part of the bank, within a layer of relatively permeable material. Water is removed from the bank via internal drainage points that pass through discharge outlets.

The principal variations for subsurface drainage are longitudinal drainage pipe with lateral outlets, multiple lateral drainage pipes, longitudinal trenches filled with gravel and weep holes through rigid revetments

Application

- reduce the development of rapid drawdown conditions that may lead to bank slumping and damage to infrastructure
- lower water table and control piping of bank material
- remove build-up of subsurface water pressures

Limitations

- drainage may lower stream bank watertable and affect vegetation
- drainage pipe outlets may be damaged or blocked by debris, erosion or sedimentation
- vegetation roots may block perforated drainage pipes
- riparian habitat may be damaged during construction

Design and Construction Considerations

1. Most civil and geotechnical engineering textbooks provide design guidance for subsurface drainage systems.
2. Other points to note:

- examine bank stratigraphy to identify permeable layers and soil zones that are susceptible to mass movement or piping
- drainage pipes are normally installed at the base of the susceptible zone or in the permeable layer
- longitudinal or lateral drainage configurations may be used
- commonly use perforated drainage pipe, wrapped in geotextile filter sock and embedded in a sand filled trench
- longitudinal drains are commonly installed from a berm that is cut 1 to 2 metres above the adopted drain level
- lateral drains may be trenched or installed through curved holes formed from the top of the bank with directional drilling equipment
- outlet pipes in the stream should be placed above base streamflow height, protected from scour and impact damage and from vermin entry
- outlet pipes should be inclined to drain naturally and aligned slightly downstream to prevent streamflow forcing water into the pipes
- provide pipe end caps and weep collars for lateral drainage pipes to prevent washout and piping failure
- provide pipe flushing facilities
- use native species where revegetation of bank and riparian margin is undertaken, but take care that roots do not clog drainage pipes

Combinations

Subsurface drainage is commonly combined with other bank stabilisation and protection treatments such as bank battering and berms, and rock revetment. Vegetation may be used but care should be taken in placement to avoid fouling the drainage pipes.

Comments

Longitudinal drainage pipes are most commonly used, but lateral drainage pipes are under trial. Lateral drainage may be suited to installation from the top of the bank at steep sites where access is difficult and in banks having multiple drainage layers.

The effect of removal of subsurface water on the performance of vegetation is unknown. Where carefully undertaken, subsurface drainage allows full restoration of ecological values.

Treatment Characteristics

Subsurface Drainage

Bank Protection and Stabilisation Strategy

Physical

Hydrological & Hydraulic

- increases the rates of rise and fall of subsurface water levels
- high velocities and turbulence are possible around pipe outlets
- streamflow directed into underdrainage outlets may increase bank inundation

Geomorphological & Geotechnical

- stabilises bank by lowering water table, thus limiting surcharge and reducing porewater pressures
- usually has minimal direct effect on channel form
- usually used in combination with other treatments (bank battering, revetments, vegetation) which exert greater influence on channel morphology
- when placed deep in the bank, may increase the effectiveness of vegetation as a bank stabilisation strategy by lowering the water table and forcing roots to penetrate deeper
- may be vulnerable to scour around outlet

Ecological

Instream

- has minimal impact once the site has recovered from works disturbance
- revegetation of bank is necessary to rehabilitate normal cover, shade and organic input
- retains vital land/water interface
- retains fish passage along the stream
- may cause localised discharge of chemicals, nutrients and sediment

Riparian

- construction may damage habitat
- native revegetation of bank provides habitat diversity and allows rehabilitation of bank and corridor continuity
- without revegetation, riparian community becomes dominated by weeds
- roots of riparian species may affect drainage performance
- maintains access for animals to stream, bank and floodplain habitats (depending on ancillary bank protection)

Socio-economic

Social

- low impact on scenic and recreational values

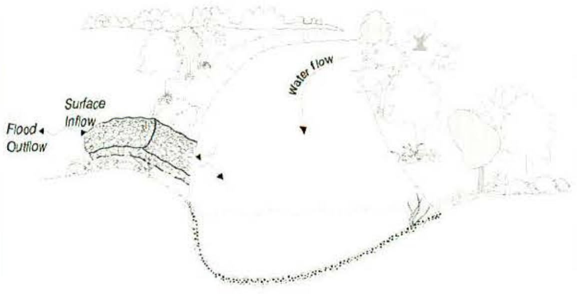
Economic

- moderate to high investigation and design costs
- low to moderate construction costs

Treatment Description

Bank Chute & Spillway

Bank Protection and Stabilisation Strategy




Grouted rock chute on urban stream in Townsville


Rock spillway on Herbert River near Ingham

Description

Bank chutes and spillways armour the upper and adjoining sections of the bank where overbank flows are channelled into or out of the stream. Bank Chutes armour the top and inside of the bank to protect against erosion from inflow to the stream. They are provided at drainage inlets from road table drains etc. Spillways armour the top and outside of the bank to protect against erosion from flood outflow.

The principal variations in material for bank chutes and spillways are rock, concrete, rock gabions and mattresses.

Grass banks and grass reinforced with geotextile mats are also used in milder overflow conditions.

Application

- protect tops and slopes of stream bank against fluvial erosion from drainage inflow (bank chute) and overbank flow (spillway)
- control avulsive stream channel courses
- protect land and utility

Limitations

- may cause erosion at structure outlet unless adequately protected
- may cause disturbance to habitat during construction and operation
- difficult to revegetate
- appears unnatural unless revegetated
- commonly breaks continuity of riparian vegetation corridor

Design and Construction Considerations

1. Most hydraulic engineering textbooks and drainage design manuals provide design guidance for chutes, spillways and energy dissipators. Design information for selection of rock size (based on grade control structures) is available in Standing Committee on Rivers and Catchments (1991) (Chapter 7).
2. Other points to note:

- provide energy dissipators where necessary at outlets to chutes and spillways
- provide abutment and bank protection to prevent outflanking and undercutting
- avoid using impermeable revetments that block subsurface water drainage from the bank
- for construction in rock, use rock with good durability and avoid using rock with adverse chemical characteristics that affect water quality
- construct bank overflow (invert) level lower than adjoining levee/top of bank
- provide hydraulic cutoffs beneath structures to prevent piping failures
- specify revegetation of bank and riparian margin using native species

Combinations

Vegetation and rock revetments are commonly used in conjunction with bank protection and stabilisation treatments such as bank chutes and spillways.

Comments

With careful design of bank chutes and spillways, ecological values can be maintained and only minor impact sustained. Revegetating the riparian corridor will ultimately minimise the effects of overbank flows.

References

Standing Committee on Rivers and Catchments 1991, *Guidelines for Stabilising Waterways*, prepared by the Working Group on Waterway Management, Victoria.

Treatment Characteristics

Bank Chute & Spillway

Bank Protection and Stabilisation Strategy

Physical

Hydrological & Hydraulic

- may impede subsurface water drainage
- increases overbank velocities through treated area
- high velocities and turbulence may occur at the structure outlets

Geomorphological & Geotechnical

- protects bank by armouring with coarse materials
- fixes local bank position
- may modify channel migration
- transitions to untreated bank may be vulnerable to scour and undercutting
- revetment materials may be mobilised and exacerbate erosion through abrasion and current deflection during high overbank flows.

Ecological

Instream

- maintains fish passage along the stream
- minor impact on instream system

Riparian

- protects bank and vegetation but creates break in riparian corridor (but a smaller break than might occur with unconstrained flooding)
- native revegetation of sections of the bank will reduce effects of loss of riparian vegetation
- without revegetation riparian community becomes dominated by weeds

Socio-economic

Social

- large reduction in scenic values

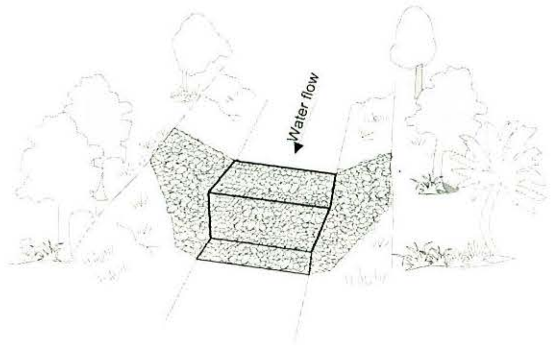
Economic

- moderate to high investigation and design costs
- moderate to high construction costs
- majority of construction by heavy machinery

Treatment Description

Bed Chute & Drop Structure

Grade Control Strategy



Rock gabion drop structure on Rankin Creek (Atherton Tableland)

Description

Bed chutes and drop structures are armoured drops in the bed of small streams that protect the streambed against erosion. They are usually placed in straight sections of the stream and have abutments protecting the stream banks. Single structures or a series of structures may be used. Bed chutes are graded drops in the bed, normally of flexible construction. Drop structures are vertical or near vertical drops that may be rigid or flexible.

The principal variations in material are rock and rock mattresses (bed chute); concrete and rock gabions (drop structure). Grass banks and grass reinforced with geotextile mats are also used in milder flow conditions for bed chutes.

Application

- dissipate energy through steps in stream bed profile
- prevent bed head-cut from moving upstream
- reduce grade in sections of a stream between structures
- reinstate stable bed profile by deposition between structures
- control of avulsive stream channel courses

Limitations

- usually only used in small streams
- turbulence may cause erosion to bed and banks downstream unless adequately protected
- may restrain natural bed incision processes
- fish passage will be restricted in drop structures and possibly in bed chutes
- may alter in-stream habitat if water ponds upstream
- restricts boating activities

Design and Construction Considerations

1. Design information for bed chutes and drop structures is included in Standing Committee on Rivers and Catchments (1991) (Chapters 2 and 7). Most hydraulic engineering textbooks and drainage design manuals provide design guidance for chutes, drops and energy dissipators.
2. Other points to note:

- structures should be located to provide stable stream bed grades between structures
- avoid locating structures close to bends, in major expansions or contractions, or near tributaries
- provide abutment and downstream protection to prevent outflanking and erosion
- provide hydraulic cut-offs beneath structures to prevent piping failures
- provide passage for fish and other instream fauna
- specify revegetation of bank and riparian margin using native species

Combinations

Vegetation is commonly used in conjunction with grade control treatments to increase flow resistance, dissipate energy and protect stream banks. Rock revetments are commonly used in conjunction with bed chutes and drop structures to protect abutments against erosion.

Comments

Bed stabilisation by grade control is often an important prerequisite for overall stream stability.

Fish passage can be severely restricted by drop structures. Impact on ecological values can be minimised with careful design and appropriate revegetation (including upstream and downstream of structure).

References

Standing Committee on Rivers and Catchments 1991, *Guidelines for Stabilising Waterways,* prepared by the Working Group on Waterway Management, Victoria.

Treatment Characteristics

Bed Chute & Drop Structure

Grade Control Strategy

Physical

Hydrological & Hydraulic

- causes localised acceleration of streamflow
- causes high velocities and turbulence downstream and at abutments
- high velocities and turbulence may occur downstream of the structure
- may increase upstream water levels and increase risk of flooding

Geomorphological & Geotechnical

- inhibits local incisions of the stream bed and over-steepening of the banks
- stops upstream migration of bed incisions, introducing local changes in stream grade
- bed chutes may be used to simulate pool and riffle sequence
- ponding upstream of structure may promote sediment deposition
- stream may have excess sediment transport capacity downstream of structure, leading to localised scour and erosion
- eroded sediment may be deposited downstream, causing aggradation
- may be bypassed by migrating channels

Ecological

Instream

- may introduce alien substratum (hard structure) but...
- may increase habitat diversity locally
- slows flows upstream of structure and promotes sedimentation and growth of aquatic vegetation (drop structure)
- or minimises growth of aquatic vegetation (bed chute)
- may damage bank vegetation
- provides local barrier to vital land/water interface
- may act as a barrier to normal animal movements; this effect minimised by careful design to allow passage during floods

Riparian

- should allow maintenance of riparian habitat diversity
- upper bank typically unchanged (unless disrupted during construction)
- lower bank is changed
- large abutments will break vegetation corridor
- abutments may restrict access for animals to stream, bank and floodplain habitats
- reduction of shade and cover and organic input to stream
- allows for revegetation of upper banks

Socio-economic

Social

- high to moderate reduction in scenic values (bed chute generally has less impact than drop structure)
- may reduce boating opportunities, particularly drop structures

Economic

- moderate to high investigation and design costs
- moderate to high construction costs
- majority of construction by heavy machinery

Appendix D - Checklist of Tasks for 'Best Practice' Stream Stabilisation and Rehabilitation

This section provides a list of tasks and issues to be considered in the planning, design and implementation of stream stabilisation and rehabilitation projects. It is essentially an *aide-memoire* - to be used during the ten-step process (Chapter 3). This checklist of actions should be consulted for each project, but it is likely that only a subset of the list will be relevant to any particular situation.

1. Consider local, regional, state and federal legislation and policies

- Address relevant legislation and obtain necessary agency approvals.
- Consult Department of Natural Resources (Queensland) with respect to integrated catchment management, non-tidal waterways, crown land and Native Title.
- Consult Department of the Environment (Queensland) regarding tidal waterways, conservation areas, protected flora and fauna, and cultural values.
- Consult Department of Primary Industries (Queensland) Fisheries Group with respect to mangroves in tidal waterways, fish habitat and marine resources.
- Consult Main Roads Department (Queensland) if relevant.
- Consult local authority and river improvement trust.
- Consult Wet Tropics Management Authority if relevant.
- Consult federal and state government agencies administering federal funding projects such as the Natural Heritage Trust.
- Check the need to consult other government agencies as appropriate.

2. Check stakeholder agreements, historical, archaeological and cultural interests

- Consult with, for example, groups and individuals representing government agencies, local authorities, industry groups, catchment management, landcare, conservation, landholders and the general community.
- Check importance of the site to indigenous and non-indigenous people.
- Clearly identify significant sites, and ensure that contractors are aware of their importance and avoid disturbing them.
- Address site-protection measures in the construction management plan.
- Check amenity values of the site and avoid disrupting them.

3. Consider spatial and temporal aspects of work

- Identify *early in the planning and design process* what the construction impacts and ongoing consequences of the remediation are likely to be.
- Determine the influences of stream- and section-scale processes and their impacts on stabilisation works. Will localised works simply relocate the problem? Is the problem due to normal processes which cannot be prevented in the long term?
- Assess the extent of disturbance caused by treatments to habitat in relation to the size of stream. Will the proposed works affect a large proportion of a reach? Could they disrupt the continuity of the instream habitat (eg. for fish migration) or of the riparian habitat (eg. for bird and mammal dispersal)?

- Determine the duration of construction impacts – are they short- or long-term? (long-term may, for example, prevent fish passage).
- Determine whether or not the project outcomes could be improved by scheduling works appropriately (eg. avoiding wet season disruptions, irrigating through the dry season to stabilise prior to the wet season).

4. Use techniques that are appropriate to the location and purpose

- Design in accordance with accepted standards, and according to recommendations in these guidelines.
- Consider both standard and innovative designs for stabilisation and rehabilitation.
- Check appropriateness of alternatives using these guidelines.
- Ensure treatment construction minimises disturbance to the bank, the stream and native vegetation.
- Use existing topography to minimise modification of stream morphology.
- Allow for construction to be undertaken in stages where necessary.
- Reduce exposure time of sites subject to damage.
- Design and implement an erosion and sediment control program where appropriate.
- Design and implement soil and water management plans where appropriate.
- Ensure that native vegetation is retained.
- Provide temporary vegetation or ground cover where necessary.
- Plan revegetation requirements in conjunction with planning of construction.
- Obtain revegetation advice from local revegetation groups where appropriate.
- Where adjoining riparian land has been cleared or severely degraded, negotiate with landholders to reclaim a strip of land and re-establish an 'esplanade' of riparian vegetation.

5. Minimise disruption to habitat and ecosystem function

- Determine ecological conservation values of site/section locally, regionally, and nationally, and determine nature and extent of threat to these values.
- Ensure protection of critical areas and ensure that contractors aim to preserve ecological values.
- Minimise disturbance to natural vegetation (ie. loss of habitat and exposure of soil to erosion) to sustain normal plant and animal communities and ecosystem processes. Avoid discontinuities in bank vegetation.
- Minimise disturbance to streambed and banks.
- Preserve or reproduce natural stream morphology (eg. pool riffle sequence) and degree of vegetation canopy cover where possible.
- Provide crevices and overhangs in instream structures for habitat diversity.
- Where structurally feasible, use vegetation in preference to timber; timber in preference to rock; rock in preference to concrete or steel.
- Do not use exotic plant species (they degrade habitats and disrupt natural ecosystem function). Avoid introduction of exotic plants and animals.
- Avoid using filter cloth under rock revetment where regeneration of vegetation is required.
- Minimise earthworks, avoid exposing bare earth and revegetate as soon as possible.
- Protect regeneration areas from damage by stock and people, using fencing and other means.
- Minimise impacts from heavy machinery and other construction traffic, such as soil compaction, erosion of stream banks and beds, and introduction of exotic species and contaminants.
- Preserve hollow-bearing trees, which provide important shelter and breeding habitat for many native animals.

- Minimise clearing of the instream vegetation and of snags that provide habitat and perches for animals.
- Avoid discharges of pollutants into the atmosphere, soil and water, as they may severely degrade plant and animal communities.
- Avoid activities that affect downstream water quality and avoid downstream releases of poor quality water.
- Ensure that all flow modification, diversion, and change in ground and surface water levels will continue to accommodate the water requirements of ecological systems and other instream beneficial uses.
- Recognise that many sites are already partly degraded from human impacts and are highly vulnerable to construction impacts. Restoration of previously degraded sites may be a positive environmental outcome.
- Protect the watercourse from erosion and sedimentation by using appropriate erosion control mechanisms during construction.
- Develop construction management plans to minimise adverse impacts of construction.

6. Maintain aesthetic and recreation values

- Where necessary, allow for access to and passage along stream for boating.
- Maintain and enhance ecological and aesthetic value for direct contribution to recreational experience.

7. Control disposal of industrial and domestic refuse and of contaminated soil

- Control disposal of all wastes (waste disposal can affect the aesthetic value of the site; pollute soil, water and air; and result in public complaints and damage to ecosystems).
- Prevent spillage of fuels, chemicals, fertilisers etc. that might contaminate soils.
- Keep site clean and tidy at all times and leave in this condition once construction is completed.
- Define how refuse is to be collected, stored and removed from the construction site.
- Note that clean-up of contaminated sites is expensive and time-consuming and can delay the construction process.

8. Avoid problems from dangerous goods on construction sites

- Remember that dangerous goods can pollute waterways and air, can contaminate soil and may be a fire hazard.
- Develop a management plan and follow regulations for safe manufacturing, transport, storage, use and disposal, of dangerous and flammable goods.
- Develop a management plan for remedial actions should contamination occur.
- Describe appropriate control measures in the contract documents.

9. Site rehabilitation works

- Provide a rehabilitation plan that includes control of potential erosion areas, revegetation, etc.
- Ensure that the contractor undertakes site rehabilitation on completion of stabilisation works.
- Note that site rehabilitation works may temporarily affect aesthetic values of the area and may lead to serious problems of erosion, sedimentation and modification of stream flows if not managed appropriately.
- Ensure careful removal of temporary structures.
- Loosen compacted bare soil.
- Control weeds using weed control matting, weed spraying or revegetation.
- Reinstate original soil surface levels, and create soil disposal mounds or borrow pits that blend into the existing landscape.

- Reinstate the original topsoil as it contains native grasses and seeds that will re-establish and complement sown species.
- Rehabilitate any damage to streambed and banks caused during construction.
- Revegetate exposed banks and surrounding areas immediately after completion of construction, using local native species.
- Remove access tracks and other hard standing areas.
- Provide fences to protect regeneration areas from stock and the general public.
- Monitor rehabilitation area to evaluate effectiveness of controls used.

10. Build in environmental guidelines to the construction contract

- Write environmental guidelines into construction contracts.
- Ensure that impact minimisation procedures are included in all project specifications.
- Ensure that an appropriate set of contract conditions to protect the environment from careless construction practices is clearly laid out and explained to staff.
- Monitor contractors' performances.
- Take environmental impacts into account throughout the construction process.
- Ensure that contractors, sub contractors and relevant consultants operate according to agreed environmental principles and management systems and procedures.
- Ensure that all practical measures are taken to mitigate impacts (this will reduce the requirement for restoration).

11. Develop a personnel training and awareness program

- Develop an educational program before construction, to ensure personnel are aware of environmental issues and features of site.
- Explain why personnel must follow environmental guidelines and minimise disturbance to the environment - instill the necessary commitment.

Glossary

abrasion	process of wearing down or wearing away by friction.
abutment	portion of a structure that is in contact with a stream bank.
accelerated erosion	an erosion rate that, due to human interference, exceeds the natural rate.
accretion	increase in the area of land as a result of sedimentation.
Adopted Middle Thread Distance	(AMTD), distance upstream from the mouth of a stream, measured along the middle of the stream.
AEP	(Annual exceedance probability), probability of exceedance of a given instantaneous discharge, eg., within a period of one year.
afflux	an increase in water level at a designated flow, due to an obstruction in or across a stream, eg. culverts.
aggradation (bed)	progressive build-up or raising of the stream bed due to sediment deposition.
alignment	path of the main flow in the stream.
alignment training	stream stabilisation works that introduce resistance to parts of the stream channel, or use hydraulic structures, to alter the flow alignment.
alluvial fan	depositional landform that develops a fan shape as a stream exits a confined point, spreads out and decreases channel depth and flow velocity.
alluvium	unconsolidated sediment that is or has been entrained and deposited by running water.
anabranch	a distributary stream channel.
anastomosing channels	streams adopting a complex channel pattern that exhibits both braided and meander characteristics.
angle of internal friction	maximum angle at which material such as loose rock, sand, or silt will remain stable.
aquifer	a subsurface water bearing formation that will yield water to bores, wells or springs.
ARI	(Average recurrence interval), average or expected value of the period between exceedences of a particular instantaneous discharge, for example.
armour	a surface layer of coarse stream bed sediments that overlies finer sediments and protects the stream bed from erosion.
avulsion	an abrupt change in stream course, and consequent abandonment of the pre-existing channel, usually as a result of aggradation.
bank	side slope of a channel within which the streamflow is normally confined. Typically, the area between the change in slope marking the edge of the floodplain (the top) and the change in slope marking the edge of the bed (the toe).
bank chute	armouring of the top and inside of the stream bank to control erosion from inflow to the stream.
bank protection and stabilisation	structure or vegetation placed on the face and toe of a streambank for protection against fluvial erosion and/or mass movement.
bankfull discharge (Q)	a discharge that just fills a stream channel without flowing onto the floodplain.
bar	a temporary deposit of sediment within a streambed that may be exposed only during low-water periods.
baseflow	streamflow that is not directly affected by rainfall, but may be maintained by groundwater recharge, or by reservoir releases.

battering	artificial slope formed to improve bank stability or as preparation for other stabilisation works.
bed	bottom of a stream channel.
bed chute	graded drops in the bed of small streams, usually armoured with rock and placed in straight stream sections.
bed control	an erosion-resistant section of stream bed that prevents short term bed degradation and bed slope changes.
bed slope	longitudinal gradient of the streambed.
bedload	sediment load that is not in suspension - ie rolling, sliding or bouncing along the bed. See also suspended load.
bedrock	rock in a stream bed or banks that is resistant to erosion over long periods of time.
bendway weirs	submerged structures placed on the stream bed on the outside of a bend, designed to maintain channel depth and redistribute secondary currents away from eroding banks.
berm	an artificial bank usually created to improve stability and/or to provide construction access.
biodiversity	full variety of organisms living in a particular area, including genetic variation within species as well as species diversity.
borrow pit	source area for natural materials used in bank construction.
boulder	a natural stream particle that is retained on a 200mm sieve.
braided stream	a relatively wide and shallow alluvial stream with multiple channels formed by islands and bars that represent the intertwining plaited effect of braid.
breakout (breakaway)	low section of a stream bank where flood waters have exited the stream channel. See also avulsion.
buffer	an undisturbed zone between a stream and an adjoining land use.
capacity (stream)	maximum amount of liquid, solid or dissolved material that a stream can carry under a given set of conditions.
catchment	topographic area that drains into a stream at a specific location as defined by all land sloping towards the channel and its tributaries.
channel	a natural or artificial waterway that continuously or periodically conveys water.
channel bar	an elongated instream deposit usually associated with braided river patterns.
channel bench	an alluvial, often vegetated, instream bench which is only visible at low water levels.
channelisation	realignment, straightening, widening, deepening and lining of waterways that is commonly undertaken as a means of agricultural and urban drainage.
chute	an inclined artificial section of a stream bed, bank or levee through which stream flow is directed. Surface may be grass, concrete or compacted rockfill.
clay	cohesive soil with particles < 0.002 mm diameter. Often not very erodible when wet, but more prone to erosion when dry.
cobble	a particle that is retained on a 63 mm sieve but passes a 200 mm sieve.
cohesion	natural resistance of microscopic soil particles to being pulled apart at their point of contact.
colluvium	unconsolidated, geologically recent sediment that has accumulated as a result of gravity and hillslope processes.

community (biological)	an assemblage of organisms that occurs in a particular place, eg. a stream pool community.
competence	maximum sediment size a stream can transport under a given set of conditions.
confluence	point at which one or more tributaries join the main stream.
connectivity	extent and nature of linkages between patches of habitat.
conservation	management of biological resources to sustain them in their natural state.
corridor	ecological link provided by continuous strips of habitat such as riparian vegetation that allows movement and dispersal of organisms.
creek	a general term for a small stream that is not necessarily permanent but is usually a tributary of a larger stream.
culvert	a lined channel or pipe(s) that carries a waterway beneath a road, railway or other embankment.
cumecs	cubic metres per second.
current	flow of water through a stream channel.
cutoff	a stream diversion through the neck of a meander that can occur artificially or naturally.
dam	an artificial or natural blockage to the main flow of a stream that is commonly used to store water for human use.
debris	accumulation of sediment and organic material, deposited by a stream.
degradation	(a) long-term lowering of a stream bed due to erosion. (b) reduction in environmental amenity.
delta	accumulations of river derived sediment deposited at the coast where a stream enters the receiving water body, streamflow slows and sediment is deposited.
density	mass per unit volume.
deposition	settling out or laying down of suspended, in-solution, or other water-borne materials by a lessening of streamflow or by some chemical action.
depth of flow	vertical distance from the water surface to the streambed.
desnagging	removal of large woody debris, or snags, from the stream bed or banks.
detritus	dead organic material (leaf litter, etc) that usually accumulates on the bed of water bodies.
discharge (Q)	volume of water passing through a channel during a given time, usually measured in cubic metres per second (cumecs).
distributary	a channel that drains water away from the main stream.
disturbance	physical or human-induced perturbation of an ecological or physical system with significant adverse effects on animal and plant populations within the system.
diversion	any natural or artificial waterway that takes part or whole of the streamflow away from its natural course.
drainage basin	the watershed of major river systems as defined by the Australian Water Resources Council.
drainage density	ratio of the total length of all the channels in a drainage system to the total surface area of the drainage basin.
dredging	a mechanical operation in which material is removed from a stream to increase waterway area or for use elsewhere.
drop structure	vertical or near vertical drops artificially created in the beds of small streams to limit bed degradation and steepening.

dynamic equilibrium	fluctuation about a long-term average state (eg. balance between erosion and deposition in a stable stream).
dynamic system	a system in which natural processes are changing.
ecological diversity	variety of habitats, organisms and ecological processes in a particular area.
ecological impact	adverse effect of a disturbance on a population, community or ecosystem.
ecological processes	interactions among organisms, and between organisms and their environment, that relates to the use of materials, life cycles, habitat use, etc.
ecology	the science of the interaction of living things with their physical and biological environment.
ecosystem	a relatively discrete physical and biological environment and the community of organisms inhabiting it, eg. a stream or a forest.
effluent	industrial or domestic discharge from a processing or manufacturing plant into a stream, lake, channel, etc.
embankment	an artificial bank built along a stream, usually to protect adjacent land from inundation by flood waters.
embayment	permeable structure used to reclaim part of an eroded stream by obstructing stream flow adjacent to the bank; usually comprises fences in a grid pattern.
emerging insects	adult insects emerging from their larval or pupal skins; for example, terrestrial adult dragonflies emerging from their aquatic larvae.
endemic	describing species that are only found in a particular area, eg. the Freshwater crocodile (*Crocodylus johnstoni*) is endemic to northern Australia.
entrainment	dislodgment of surface particles through water pressure or impact.
ephemeral stream	a stream that flows for short periods only, in direct response to precipitation, and receives little or no water from springs or other sources.
erosion	natural or artificial removal of surface material, usually by water, wind or biological processes.
estuary	tidal, and mostly saline, part of a stream.
eutrophic	describing an aquatic system that is enriched with nutrients, often artificially, causing algal blooms, extremes of oxygen content, and other, often ecologically undesirable, outcomes.
eutrophication	process by which a water body becomes nutrient-enriched, thereby invoking algal 'blooms'.
exotic	species that are not native to an area, eg. the cane toad and rubber vine in Australia.
fauna	animals found in a particular area.
fence	low structure running parallel with the flow, used to direct flow along a new alignment away from eroding banks.
fill material	soil that is placed to bring the ground surface up to a desired level.
filter	layer of fabric, sand, gravel, or graded rock placed beneath a revetment to allow the movement of water but prevent movement of soil particles.
filter-feeder	an animal that feeds by sieving suspended material from the water.
fines	silt and clay fraction of natural sediment which passes through a 0.075 mm sieve.
flood	an increase in the volume of water carried by a watercourse or lake that inundates adjacent lands.
flood frequency	rate of occurrence of a flood of particular magnitude.

floodplain	land adjacent to streams that is regularly flooded; often includes seasonal and perennial wetlands.
flora	plants found in a particular area.
flow regime	character of the timing and amount of flow in a stream.
fluvial erosion	removal of surface and subsurface soil particles by water movement.
fluvial geomorphology	study of stream form and behaviour.
fragmentation	breaking up of habitats into small isolated patches.
freshwater	normally describing water that is non-saline, and its inhabitants; sometimes inclusive of saline inland (ie. non-marine) waters such as salt lakes.
gabion	a rock-filled wire basket used to stabilise a streambank or protect against erosion.
geosynthetic	natural or synthetic fibre cloths placed on a stream bank, either as a filter under rockwork, as soil reinforcement, or as a mat to enhance vegetation growth.
geomorphology	science of landform and landscape evolution and function.
gorge	a deep and narrow section of a river valley, usually with almost vertical rock walls.
grade	slope of a surface expressed as a ratio of change in height to horizontal distance.
grade control	stream management strategies that dissipate energy in the stream and prevent the upstream advance of stream channel deepening.
graded stream	stream in equilibrium after having adjusted its channel shape, slope, sinuosity etc, to conform with the catchment hydrology.
gravel	stone particles that are retained on a 2.36 mm sieve but pass a 63 mm sieve.
ground water	water that fills the voids in the soils, rocks, etc below the ground surface.
ground water table	subsurface water level below which the soil is saturated.
groyne	a structure (usually impermeable) projecting from the streambank, designed to increase flow resistance and direct streamflow away from the bank through a preferred channel alignment.
gully	a narrow channel worn in a hillside or on sloping ground by the action of water.
habitat	place, and its physical and biological properties, where an animal or plant lives.
habitat complexity/diversity	variety and patchiness of habitats in a particular area, and the degree of variation within habitats.
habitat degradation	reduction in habitat values (eg. diversity, complexity, water quality), leading to loss of plant and animal diversity.
headcut	a short steep section of stream bed that erodes in an upstream direction.
headward erosion	erosion upstream lowering of the stream bed, due to erosion of a headcut or knickpoint.
helical flow	three-dimensional movement of water particles along a spiral path in the general direction of flow.
herbaceous plants	plants that do not have woody stems.
hydraulic gradient	slope of the stream water surface between two points.
hydraulic jump	abrupt turbulent rise in the water surface caused by an obstruction or change in slope of the stream bed.

hydraulics	study of water and other liquids at rest or in motion.
hydrograph	a graph showing water depth or discharge over time.
hydrology	study of the occurrence, properties, related laws and use of water in streams, lakes and underground sources.
impermeable material	material that prevents the passage of water.
incised channel	a channel that has eroded its bed to the point where high banks are formed.
infiltration	that portion of rainfall or surface runoff that moves downward into the subsurface rock and soil.
instantaneous discharge	flow rate of water past a particular point in a stream, usually measured in cumecs.
instream	occurring within the stream channel.
intermittent stream	a stream that does not flow continuously.
invertebrate	any animal that does not possess a backbone eg. worms, crustaceans, molluscs and insects.
knickpoint	a change in gradient along the longitudinal profile of a stream. It may be sudden, as in a waterfall, or gradual and only detected after detailed survey. The increased slope associated with knickpoints increases downstream flow velocity and erosive power.
lagoon	an enclosed body of water possibly a remnant of a previous channel location.
larva	juvenile stage of an animal that is substantially different in form or habitat from the adult, and which changes into the adult form through a short metamorphosis (eg. tadpole).
levee	(artificial) an embankment constructed along the top of the streambank; (natural) an alluvial build-up of sediment along the streambank that is higher than the adjoining floodplain.
life cycle	development of an animal or plant, from fertilised egg through to adult, and production of the next generation.
littoral drift	along-shore movement of sand due to wind and wave actions.
longitudinal section	plot of the elevation of the channel bed, banks and water level verses horizontal distance.
low flow	normal discharge in a stream during non-flood periods. During low flow the tops of most bars are exposed.
macrophyte	any non-microscopic plant.
mass movement	movement of material under gravity. For example, the collapse of a stream bank.
mattress	flexible rock-filled wire basket used to protect the stream bank or bed against erosion.
meandering	winding path of a stream through relatively flat country.
migration (faunal)	regular and reversing movement of animals, especially to breeding or feeding grounds.
migration (fluvial)	gradual shift in stream planform due to meandering.
native	plants and animals that naturally occur in a particular area.
non-cohesive soil particles	soil particles that have no natural resistance to being pulled apart at their point of contact, eg. silt, sand, and gravel.
nutrient	a substance such as nitrate or phosphate that is required for growth and survival of plants.

organic input	organic material that is contributed to aquatic environments, especially from the riparian zone or via ground water.
organism	any living thing eg. animals, plants, fungi, bacteria or other.
outflank	erosion around the end and behind a bank protection structure.
overbank flow	water movement over the top of the bank, either as flood water flowing out of the channel or runoff from surrounding lands into the channel.
oxbow lake	the abandoned bow-shaped reach of a former meander loop.
perennial stream	a stream that flows continuously.
pest	a nuisance organism, particularly animals that are harmful to crops etc.
pH	unit of measurement of acidity of water.
physico-chemical	describing environmental variables of a physical (eg. temperature, salinity) or chemical (eg. nutrient concentration) nature.
physiography	description of the land surface.
phytoplankton	planktonic plants, microscopic algae etc.
piles	timber or concrete poles, driven into a stream bed as foundation for a bridge structure or to direct stream flow.
piping	subsurface removal of soil material through flow of water, leading to development of channel or pipes in the soil mass.
planform	synoptic, two-dimensional perspective.
plankton	small to microscopic organisms that live in the water column and which drift with water currents.
point bar	a sediment deposit that develops on the inside of a bend.
pool	a body of still or slow moving water within the stream channel.
population	all the individuals of a species living in a defined area.
rain shadow	a topographically-induced effect producing a region of low rainfall, typically on the lee side of mountains.
rapid drawdown	lowering of stream water levels at a rate faster than the streambank material can drain, creating excess porewater pressures and possibly leading to mass movement of the bank.
rapids	part of a watercourse, usually in its upper reaches, where the water drops from one level to another in a relatively short distance, and the flow is usually disturbed by rocks or other obstructions in the bed.
reach	a segment of a stream's length.
realignment	process of changing the path of a stream channel.
rehabilitation (stream)	process of improving the physical and biological condition.
remediation	alleviation of a stream management problem through stabilisation, rehabilitation or restoration measures.
restoration	structural and functional return of a degraded stream reach or site to something approximating its pre-disturbance condition.
retaining wall (bulkhead)	impermeable vertical or near vertical structure used to stabilise a stream bank.
retard	a permeable structure, suited to shallow water situations, that projects from the streambank to increase flow resistance. Constructed with materials other than rock, such as timber walls, fencing etc.
revetment	armour of a streambank for protection against fluvial erosion and stabilisation against mass movement.

riffle	turbulent, rocky part of a stream.
rip rap	heavy rock that is tipped, but not precisely placed, to provide a protective layer on an eroding streambank.
riparian	pertaining to or situated on the banks of a stream.
riverine corridor	river channel and its riparian land, including part of the adjacent floodplain.
runoff	that part of rainfall on a catchment that finds its way as overland flow into lakes or streams.
saltation	a mode of sediment transport in which particles skip or bounce along the stream bed.
sand	material retained on a 0.075 mm sieve but passing through a 2.36 mm sieve.
scour	erosive action of flowing water that removes surface material.
secondary flow	three-dimensional movement of water along a spiral path as flow passes through a bend.
sediment	material that has been transported away from its original location by wind or water action.
sediment deposition	accumulation of sediment on the channel bed and banks.
sediment load	sediment carried through a channel by streamflow.
sediment rating curve	graphical representation of relationship between sediment discharge and water discharge.
sediment yield	total sediment outflow from a drainage basin during a specific period of time; includes bedload and suspended load.
sedimentation	long-term permanent filling of a stream channel, lake or estuary with sediment.
seepage	groundwater emerging from the ground surface.
shear strength	a measure of the ability of an object to withstand forces tending to cause sliding over another object.
sheet piling	an impermeable vertical or near-vertical bank protection treatment.
silt	material that is retained on a 0.002 mm sieve but passes through a 0.075 mm sieve.
sinuosity	the degree to which a stream channel winds, which may be quantified as the ratio of the actual channel distance to valley distance (measured as a straight line) between two points.
slump	see mass movement.
snag	large woody debris (branches, tree trunks) that has fallen into a stream and which obstructs flow and provides habitat for aquatic and semi-aquatic species.
species	basic division of organisms - plants, animals, etc. - defined by the individuals' capacity to interbreed naturally and produce viable offspring.
soil stabilisation	streambank soils mixed with stabilising material such as cement or lime to increase stability and resistance to erosion.
spillway	armouring of the top and outside of the stream bank to control erosion from flood outflow from the stream.
stabilisation	fixing a stream bed or bank to restrict movement, erosion or failure.
stage	water-surface level of a stream with respect to a reference level.
stratigraphy	order and position of strata in a unit of rock or sediment.
stream	a general term for a natural channel that carries water.

stream gauging station	installation in a stream to measure and record water levels and stream discharge.
stream health	capacity of the stream ecosystem to sustain a normal suite of organisms.
streambank erosion	removal of soil particles or other material from a bank slope.
streambank	see bank.
substrate	material underlying the ground surface; the material on the bed of a stream (also substratum).
subsurface drainage	perforated pipes or trenches installed in the streambank to lower the water table, reduce subsurface pressures, and reduce the potential for slumping failures.
surface runoff	that portion of rainfall that moves over the ground toward a lower elevation and does not infiltrate the soil.
suspended load	sediment transported by a stream in suspension, that is within the body of flowing water. Typically dominated by silt and clay sized material, held in suspension by the upward component of fluid turbulence.
suspension	a mode of sediment transport in which particles are moved along above the stream bed by the force of the water.
sustainability	capacity to maintain ecological and economic viability in perpetuity, ie. to retain ecological and economic values of a resource even while the resource is being used.
taxon (pl. taxa)	different levels of groupings of organisms, eg. family, genus, species.
taxonomy	description of organisms and the placement in their appropriate taxa.
terrace	an alluvial stream flat that has been formed during a past regime, and which is inundated only during large floods, if at all. Compare with floodplain.
thalweg	line extending down a channel that follows the lowest elevation of the bed.
threshold	critical condition at which the rate of change in a stream system suddenly switches from slow to fast or from no change to a significant change.
toe	that portion of a stream cross-section where the lower bank terminates and the channel bottom or the opposite lower bank begins.
top of bank	break in slope between the bank and the surrounding terrain.
traction	combined process of rolling and sliding in which mineral and rock fragments are transported along the stream bed.
tractive force	drag on a surface caused by passing water which tends to pull soil particles along with the streamflow.
tributary	a stream that adds to the flow of the main stream in a system.
turbidity	a water quality parameter that indicates the water body's ability to transmit light; the lower the turbidity, the clearer the water, and the better the light transmission.
turbulence	motion of fluids in which local velocities and pressures fluctuate in a random manner.
unconsolidated	unconsolidated not cemented, solid.
undercutting	scour at the toe of a bank that results in bank steepening or overhanging.
vane dykes	series of structures placed in the stream channel, designed to direct the principal stream flow away from eroding banks and redistribute secondary currents, thereby minimising erosion.
vegetation	(1) all plants in a defined area. (2) woody or non-woody plants used to stabilise a stream bank and reduce erosion.

vegetation structure	the 'architecture' or complexity of the vegetation (its height, how many distinct layers it has, etc.), which have a major bearing on its habitat values.
velocity	speed at which water travels in a particular direction. It is the dominant factor that influences erosion, transport and the deposition process.
vertebrate	any of the animal groups characterised by the presence of a backbone-(eg. fishes, amphibians, reptiles, birds and mammals).
voids	spaces between solids in a material.
water quality	a broad term describing the composition of water, including dissolved and suspended contaminants.
water table	water level in an unconfined water body at which the pressure is atmospheric.
watercourse	depression along which water flows but not necessarily continuously.
watershed	boundary of a catchment; the dividing line between two catchments or stream systems.
waterway	a general term for any stream, river or water course, either flowing, not flowing or dry; it also includes artificial cuts, channels, canals, etc.
wave attack	impact of waves on a streambank.
weathering	*in-situ* physical disintegration or chemical decomposition of rock due to wind, rain, heat, freezing, thawing, etc.
weeds	nuisance plants, especially exotic ones, which reduce the values of natural habitats and infest crops.
weir	instream structure constructed between banks to store water, slow the current, to cause upstream sedimentation, and so help prevent scour of the bed.
wetland	a shallow water body, representing the border between terrestrial and aquatic environments, that performs important physical functions on the floodplain and provides a key life support system and diverse habitat for plants and animals.
wire mesh	woven or chain wire fabric used in construction of stream control structures.
wildlife	native plants and animals of a given area; often restricted to the terrestrial/ semi-terrestrial vertebrate fauna (frogs, reptiles, birds, mammals).
zooplankton	planktonic animals - small to microscopic shrimps etc.

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