A Simple Model to Illustrate the Effects of Riparian Revegetation on Stream Values in Large Catchments

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ABSTRACT: *Catchment managers and scientists involved in the LWRRDC sponsored National Riparian Zone Project gathered in Yungaburra, QLD in November 1994, to carry out a workshop aimed at developing a program of integrated research to meet management needs. The workshop was focussed around the production of a computer model of the North Johnstone River Catchment, which indicates the response of stream values to riparian vegetation management. We used the Adaptive Environmental Assessment and Management (AEAM) approach to define and develop the model. The model includes expert knowledge on how riparian vegetation affects sediment and nutrient filtering, bank erosion and terrestrial and in-stream ecological habitat.*

1. INTRODUCTION

The management of riparian lands has become an important issue in Australia. In response to the concerns of many government agencies and community groups, the Land and Water Resources Research and Development Corporation (LWRRDC) commissioned a national research program on the rehabilitation and management of riparian lands. The program aims to:

- identify and quantify the effects of riparian lands on channel morphology, bank stability, and the ingress of sediment and nutrients to rivers and water bodies;
- identify the key processes by which riparian lands influence in-stream ecosystems and their functioning, and quantify major effects;
- demonstrate practical, cost effective and ecologically sound methods for rehabilitation and management of riparian lands.

It involves researchers from a wide range of disciplines and institutions, as well as managers and practitioners from state agencies and local land care groups. Details of the National Riparian Zone Program (NRZP) are given by Wilson *et. al.* (1995).

The objectives above reflect the fact that riparian vegetation provides numerous functions (Herron, this volume). Most Australian streams have been cleared of all or most riparian vegetation. Great effort is now going into restoring these lands. Many kilometres of streamlines are being fenced and revegetated with little understanding of the impact that will follow. Our hope is that stream banks will stabilise, water quality will improve, fish will spawn, terrestrial fauna will flourish, the land will look good, and the landholder will benefit from his or her efforts.

To ensure these outcomes we need to optimise the design of riparian restoration projects to perform a range of functions. This requires understanding the physical and ecological processes which occur in the zone, and the links between those processes. It also requires an understanding of the needs of, and management constraints experienced by landholders.

2. WORKSHOP OBJECTIVES

In light of these issues, the participants in the NRZP felt that an important first step in a large management oriented research program was to bring together managers, practitioners and researchers in a workshop setting to identify each party's expectations, requirements and expertise. The workshop focussed on formalising our collective understanding of how riparian vegetation works to enhance stream values, within the framework of a computer model.

The workshop was not however, primarily designed to be an exercise in model development. The intention was to use the *process* of developing a systems model to identify and explore our understanding of the physical and ecological responses occurring in riparian zones at time and space scales relevant to management. Our specific objectives were to:

- develop strong links across research disciplines and establish an integrated approach for carrying out field investigations and model development;
- develop a computer model which predicts the likely impact of riparian land management on stream water quality, stream bank stability, and in-stream and terrestrial ecology;
- determine previously unidentified knowledge gaps and research tasks from "holes" in the model and assess how these new tasks fit into the research program;
- identify common data requirements for both the ecology and physical research groups, and determine how can we use existing data sets;
- design field experiments and demonstrationsites which link ecological and physical program objectives with practical management options.

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3. WORKSHOP METHODS

The style and objectives of the workshop were based on the Adaptive Environment Assessment and Management (AEAM) process developed by Carl Walters and others. It is a technique which facilitates "...the development and exploration of management options for complex systems and is particularly applicable to environmental issues." (Grayson *et. al.*, 1994).

AEAM typically involves a workshop at which participants from diverse interested groups define and build a computer model for a system that requires management. These people may include scientists, planners, resources managers and competing resource users. The process aims to embed the best available technical knowledge in a model that addresses the issues of the group. It can be used to run a range of scenarios which lead to a set of management actions that meet the needs of, or are acceptable to, most of the interested parties.

In our case, the interested parties are the scientists and resource managers (including farmers) involved in the riparian zone program. In particular, we focussed on the development of a computer model to predict the environmental impacts of riparian vegetation management in the North Johnstone River Catchment, Queensland.

This catchment was chosen for several reasons: 1) it is one of the riparian zone program "focus" catchments, 2) relevant ecological research was under way in the catchment; and 3) QDPI had developed a substantial knowledge base for the catchment which included (i) sediment and nutrients production and transport rates on pasture, cane and banana lands; (ii) a GIS containing a wide range of relevant parameters; and (iii) long term groundwater, stream flow and water quality data sets.

In preparation for the workshop, participants were asked to think broadly about the riparian zone in relation to the following questions: 1) What can be managed in the riparian zone (eg. stock access, vegetation composition), 2) what indicators of the system can be used to assess whether the change has had an effect, and 3) what are the relationships between what can be changed and the indicators that measure the impact of the change on the system?

Participants were also asked to bring specific information to the workshop as given here:

Ecological Information:

- Water quality targets (solute and sediment concentrations, temperature, etc.) required to support desired in-stream ecosystem for a given stream type/order.
- In-stream habitat requirements (woody debris, bed material size, undercuts).
- Relationships between riparian vegetation (type, age, height) and habitat suitability (food, shelter, algal growth).

Water Quality and Quantity Data:

- Storm based data of N, P and sediment concentrations at several stations for a range of catchment types (size and land use) and flood size.
- Monthly rainfall, stream flow and turbidity data for a period of 5 years, including wet and dry years.
- Long term trends in surface and subsurface water quality parameters.
- Water quality targets set by the State or other groups.

Source Strengths and Material Pathways:

- Production rates of N, P and sediment from different land use for normal and best practice management conditions.
- Proportions of water, N and P that move through subsurface and overland pathways to streams.

Catchment Management:

- Trends in land use over time.
- Timing of significant land use changes (eg. green cane harvesting widely adopted)
- Information on actual riparian rehabilitation projects in place or planned.
- Air photography and 1:50,000 maps of the catchment.

Physical Processes:

- Statistics on amount of catchment draining through riparian zones on different order streams for grid cells.
- Relationships between riparian zone vegetation type and dominant flow pathways.
- Surface and subsurface sediment and nutrient trapping efficiencies for different vegetation types and widths.
- Relationships between riparian vegetation type, channel geometry, channel migration rates, and gully erosion rates.
- Effect of riparian vegetation on flood hydrographs.

Other:

- Experimental designs
- Several management scenarios.

A subset of this information was available, and a smaller subset was in a form that could be brought to the workshop. This information formed the basis of the algorithms incorporated into the riparian zone model.

The workshop was held at Lake Eacham Hotel in Yungaburra, Queensland on the 9th through the 10th of November 1994. Each of the workshop participants

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developed and presented data, algorithms (sediment trapping, bank stability, stream order statistics, stream temperature) or other information (farmer behaviour, process descriptions) relevant to how vegetation affects processes in the riparian zone. This information was coded into an existing base model during designated workshop sessions. A series of riparian management scenarios were run using the computer model during the last sessions of the workshop.

4. SUMMARY OF ALGORITHMS

A grid-based digital elevation approach is used to drive the suite of hydrologic, erosion and ecological processes in the model. A 930 km^2 area of the North Johnstone River Catchment was represented, covering a region which includes gauging stations at Glen Allyn and Tung Oil (Figure 1). Elevation, land use, rainfall isohyets and geology are distributed through the catchment at the resolution of 1 km grid cells. These data were extracted from 1:1,000,000 topographic maps and information presented in the Johnstone River Catchment Atlas (QDPI,1993).

4.1 Hydrology

The model uses a single bucket approach to calculate the runoff in each cell. The water balance for each cell is calculated on a monthly basis from pan evaporation data and rainfall at Innisfail. Pan data have been modified to give potential evapotranspiration via the monthly relationships of Chiew and MacMahon (1992), and rainfall at Innisfail is distributed across the catchment using annual isohyets. The water balance is calculated as follows:

$$R = \alpha S + X \quad \text{and} \quad S = I - E$$

where R is monthly runoff, a is a seepage factor, S is the monthly store of moisture in the soil, X is overland flow generated when the store is full, I is rainfall and E is actual evapotranspiration. Maximum evapotranspiration is allowed to be 75% of the maximum soil water store. Runoff is routed through the catchment along flow paths calculated using the steepest descent method. All runoff that is generated during a given month is assumed to reach the outlet of the catchment by the end of that month.

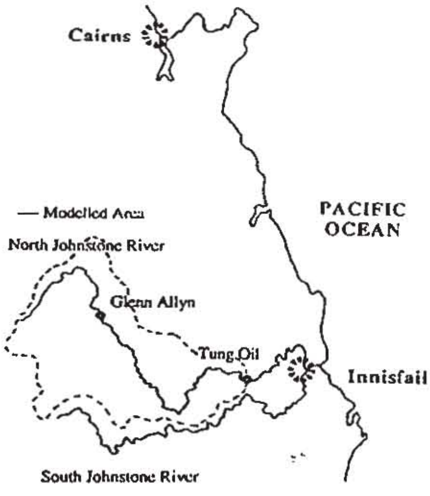

Figure 1. Location map for modeled portion of the North Johnstone River Catchment, QLD.

Adjustment of α and the maximum soil store S, were used to fit modelled runoff to observed streamflow at Glen Allyn and Tung Oil.

4.2 Stream Order Statistics

How well riparian vegetation treats bank stability, provides shade, enhances undercut habitat, or traps sediment and nutrients depends on either the size (width and depth)of the stream being treated or the amount of hillslope runoff flowing over and through the bank of the stream. For instance: shallow rooted shrubs and grasses may work well to stabilise the walls of a small gully, but deep rooted trees may be required to slow down bank erosion in bigger streams

To predict the impact of riparian management with our model, we need to know the characteristics of the streams that flow in and through each grid cell. In particular, if we want to calculate the cost of fencing the streams in part of the catchment, the length of stream running through the grid cells in the treated area is required. If we want to manage different streams in a cell with different types of vegetation (grasses and shrubs on small gullies and trees on big streams) then we need to know the distribution of stream sizes flowing through that cell. Finally, in order to predict how much sediment and nutrient can be trapped in grass filter strips along stream lines, we need to know how much material is delivered to the riparian zone from hillslopes. For this we need the proportion of hillslope runoff that flows into different stream types located in that cell.

In the riparian zone model this was achieved by constructing a set of tables which provide a statistical representation of the stream network within each 1 km grid cell. Stream data was extracted by hand from 1:50,000 topographic maps of the region. The tables uses the concept of stream order as a surrogate for stream size, since it is easy to calculate stream order, but impossible to measure stream geometry, from a 1:50,000 map.

A separate table in the model gives the relationship between stream geometry (width and depth) and stream order. This relationship was based on a quick field trip around the Yungaburra countryside during the workshop. We did not attempt to explicitly represent every stream in the North Johnstone Catchment, because it would require the use of a much smaller grid size and more complex runoff routing algorithm.

4.3 Sediment and Nutrient Generation and the Effect of Riparian Vegetation on Material Trapping

The riparian zone model includes 29 different land use types. Each land use has been assigned sediment and nutrient generation values in units of mg/l. These base level concentrations are used for runoff values less than 10 cm/month. If runoff in a cell exceeds 10 cm/month then concentrations of sediment and phosphorous in runoff increase in a non-linear manner:

$$C = C_{base} R^{\beta} \quad \text{and} \quad S_{gen} = CR$$

where C (mg/l/km^2) is the concentration of sediment or phosphorous in the runoff generated in a given cell, C_{base} is the base level concentration, R is runoff, β is the coefficient used to increase sediment and nutrient generation as runoff increases, and S_{gen} (mg/km^2) is the amount of sediment generated in a cell during a month.

The model does not aim to accurately predict sediment and nutrient generation rates. Although real sediment concentration data was used to get an approximate value of b where it was available. The concentration equation only attempts to calculate a reasonable amount of material which is delivered to the riparian zone. Trapping algorithms then calculate how different vegetation management scenarios may modify the concentrations of materials that pass through the riparian zone.

Trapping is achieved in the model using a sediment and nutrient delivery ratio approach. The delivery ratio algorithms are derived mainly from a review of grass filter strip literature (see Hairsine, this volume). The main factors affecting delivery ratios which are included in the model are: 1) the type of riparian vegetation, 2) the width of the buffer strip, 3) nutrient enrichment values, 4) the presence or absence of stock in the riparian zone, and 5) and stock access to the stream.

The model calculates the amount of sediment entering the stream, S_{stream} (mg/km^2), as follows:

$$S_{stream} = S_{gen}(SDR)$$

SDR is given as:

$$WDR * [1-(1-(GCF*UCF*CCF)*(1-SIF)*(1-SAF))]$$

where WDR is the width delivery ratio, GCF, UCF and CCF are the ground, understorey and canopy cover factors respectively, SIF is the stock influence factor and SAF is the stock access factor. Under ideal conditions of a wide dense grass buffer strip, mature rainforest next to the stream, and limited stock presence, SDR can be as low as 0.15. If there is no buffer strip, then all material delivered to the riparian zone goes through it and into the stream and SDR=1.

The amount of nutrient (phosphorus) entering the stream, N_{stream} (mg/km^2), uses a nutrient delivery ratio, NDR, and is calculated in a similar manner:

$$N_{stream} = N_{gen} * NDR \quad \text{and} \quad NDR = SDR * ER$$

where N_{gen} (mg/km^2) is the nutrient generation rate and ER is a soil dependent enrichment ratio. The sediment delivery ratios for different vegetation types is given in Table 1 below.

4.4 The Effect of Vegetation on Stream Hydraulics and Stream Bank Erosion

Vegetation affects channel morphology by influencing flow and by increasing the strength of the banks. The influence of vegetation on both velocity and bank resistance varies with the scale of the stream. In general, a suite of riparian vegetation is about the same size throughout a stream network, while the forces that are applied to the stream bed and banks tend to increase downstream.

In the model we allocate an index value to represent the influence of vegetation upon bank erosion rates. This bank erosion index (BEI) is a measure of the importance of vegetation. Thus a BEI of 0 means vegetation has no impact on erosion rates, a BEI of 5 means vegetation will dramatically reduce erosion. To account for the scale effect discussed above, the BEI varies with stream order as well as vegetation types.

The BEI is mainly a measure of the strength and resistance effects of vegetation at high flows, as this is when most bank erosion occurs. We also assume in the model that the influence of vegetation on flow velocity is small during high flows, even though it is clear that grasses and macrophytes in particular, greatly reduce low flow velocities in small to medium sized channels. Similarly, we ignore the impact of large woody debris, LWD, on bank erosion. This is because in the wet tropics LWD breaks down very quickly, and any collections of surviving wood are flushed out of the channels during cyclones.

The ratings applied in the model can be summarised as follows: riparian vegetation, including dense ground cover and overstory, considerably reduces channel erosion rates in channels of all sizes. The effect, however, declines with stream size. Groundcover alone has less effect than full rainforest, and understorey is considered to have the least effect on bank stability. The ranking adopted in the model reflect findings in the literature (see Rutherfurd *et. al.*, 1995; Abernathy & Rutherfurd, this volume).

4.5 The Effect of Vegetation on Undercutting as Habitat

Undercutting of the banks provides critical habitat in a stream. Bank vegetation allows undercutting to develop because the roots hold the bank above the toe. Without vegetation, the bank will collapse as soon as it erodes. Typically banks are undercut where there is well developed riparian vegetation (ie. rainforest species), and observations in the North Johnstone indicate this is particularly evident on third and fourth order streams. There are several explanations for this distribution:

- Grasses do not provide enough root strength to sustain undercutting.
- In small first and second order streams the root zone extends well below the toe of the stream bank so that undercutting is reduced. There may, however, be increased habitat around the roots themselves.
- The toe of the bank is just below the root zone, so the tree provides maximum support.
- In larger streams (>4 order) roots provide some support, but erosion is often below the root zone. Thus, undercutting may occur but vegetation has less influence on it.

As a result, the model is set up to predict maximum undercutting on third and fourth order streams with rainforest riparian vegetation.

4.6 Ecological Values of Riparian - Stream Linkages

Important in-stream ecological processes are both regulated and maintained by riparian vegetation. Ecological processes in forested streams including community metabolism and the structure of the major aquatic food-webs are maintained by the supply of terrestrial detritus from the surrounding catchment. This food-web typically supports a well-defined shredder and collector macroinvertebrate community. Due to low rates of primary production, the algal-scraper food-web is of lesser importance. Other inputs from the catchment including large woody debris (LWD) are an important component of both fish and macroinvertebrate habitat, particularly in sandy rivers.

Australian streams and rivers are characterised by a depauperate algal-grazing community (Bunn & Davies 1992, Davies 1993). Therefore, excessive in-stream primary production may remain largely ungrazed and, as such, not enter aquatic food-webs. Excessive primary production is typically the result of cultural impacts and includes excess macrophyte and filamentous green algal growth and blue-green algal blooms. Riparian vegetation regulates in-stream primary production by shading the channel, reducing both light inputs and water temperature. Riparian vegetation also filters inputs from the catchment, ultimately reducing nutrient levels in streams and rivers.

The importance of riparian vegetation for in-stream ecological processes is therefore based on two basic properties; (1) regulators of primary production and (2) suppliers of both energy for the maintenance of aquatic food-webs and LWD as important components of habitat.

In the model, the important features of riparian vegetation for ecological processes are:

- factors regulating in-stream primary productivity: vegetation height, and vegetation shading ability;
- factors influencing the supply of material from riparian vegetation to the stream: supply of coarse particulate organic matter (CPOM) and supply of large woody debris (LWD); and
- its ability to support terrestrial habitat for birds, other vertebrates and arthropods.

Table 1 below was developed to rank the benefits of different canopy, understory and groundcover vegetation in relation to each ecological factor listed above.

Vegetation	SDR	Height	Shade factor	LWD	CPOM	Birds	Other Vert.	Arthropods
Canopy								
Bare	1.0	0	0.0	0	0	0	0	0
Rainf. Short	0.9	10	1.0	4	10	10	9	10
Rainf. Tall	0.7	30	1.0	5	10	10	10	10
Exotic	0.8	20	0.6	2	2	2	0	0
Callist.	0.95	5	1.0	1	4	6	6	4
Understory								
Bare	1.0	0.0	0.0	0	0	0	0	0
Sparse Poor	1.0	3.0	0.4	0	2	2	2	2
Sparse Rich	1.0	3.0	0.4	0	2	4	2	5
Dense Poor	1.0	3.0	1.0	0	4	6	8	4
Dense Rich	0.9	3.0	1.0	0	4	10	10	8
Ground Cover								
Bare	1.0	0.0	0.0	0	0	0	0	0
Sparse Tuss.	0.9	0.5	0.0	0	0	0	0	0
Sparse Unif.	0.8	0.5	0.0	0	0	0	0	0
Dense Tuss.	0.7	0.5	0.0	0	0	1	2	2
Dense Unif.	0.6	0.5	0.0	0	0	1	2	2
Litter	0.9	0.0	0.0	0	1	2	4	10

Table 1. The above table shows the model rankings of different types of Canopy, Understorey, and Groundcover vegetation, for the following functions: sediment delivery, height, shade, LWD production, CPOM production, and habitat for birds, other vertabrates and arthropods.

4.7 Shading and Stream Temperature

To determine the amount of shading on the stream channel associated with different vegetation types, it was necessary to consider the width of the channel, the height of the vegetation, the shading ability of the vegetation (*e.g.* the density of the canopy cover) and the orientation of the stream. Shading ability is a function of height of vegetation, canopy density, stream width, and stream orientation.

Water temperature is also strongly affected by shading. With 100% shading in first and second order streams, water temperature was considered to decrease by 10^{0}C during summer and increase by 2^{0}C during winter (Quinn *et al.* 1993). An estimate of the shading effect on water temperature in a given cell is given by:

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$T_{cell} = T_0 - fT_s$ where

$T_0 = 19 + 9\sin 2p(\text{month}+1)/12 - 5(\text{elevation})/700$ and

$T_s = 4 + 6\sin 2p(\text{month}+1)/12$.

These equations predict T_0 to vary between 28°C in summer and 10°C in winter, where T_0 is the unshaded stream temperature in the cell, T_s is the change in stream temperature caused by shading, f is the fraction of stream shaded in the cell, and T_{cell} is the combined shaded and unshaded stream temperature for the cell. This value is flow weighted with incoming stream flow to give the temperature of the outflow at that cell. Stream temperature is treated as a conservative constituent in the system. This is crude, but gives a reasonable indication of the impact of shading on stream temperature throughout the catchment.

4.8 Output

No output from the model is presented in the paper because the AEAM base model structure is designed to inhibit hard output. This is to discourage the use of the model in a predictive mode. Screen based output includes time series garphs and maps which track system response as the model runs (Table 2).

Line Graph Choices	Map Choices
Rainfall	Soil Water Store
Runoff Ml/Month	Landuse
Suspend. Sed. (Mg/L)	Suspended Sed. Load
Phosphorous (Mg/L)	Temperature
Stream Temperature	Phosphorus Load.
Cum. Susp. Sed. (T)	Stream. Erosion
Cum. Phos. (T)	Undercutting
Cum. Sed. In Rip. Zone	Hyd. Resistance
Ecological Index	Ecological Index
Erosion Index	
Undercutting Index	
Velocity Index	

Table 2. Screen output options for the riparian zone model.

5.0 WORKSHOP OUTCOMES

The workshop resulted in the expected outcomes listed here:

- Computer model which illustrates the functions of riparian vegetation in relation to stream water quality and ecological values.
- Definition of knowledge gaps related to predicting the impact of management options on stream values.
- Definition of experimental designs to obtain best data to address management issues.
- Identification of joint experiments between ecology group and physical/chemical group.
- Definition of farm and catchment based riparian management options and indicators of their success.

Two very important, but unexpected, outcomes were:

- Opportunity for Scientists to work through physical and ecological processes in riparian zones with catchment managers, and demonstrate the need for research.
- Support of catchment managers for experimental work in Johnstone River Catchment.

The practical significance of these outcomes is that the planned research will be better targeted to meet the needs of catchment managers. The workshop was the first step in ensuring that scientists understand management questions and capabilities and that managers understand what research should be done to help them achieve better stream values. The process of model development demonstrated to both the scientists and managers the extent and depth of collective knowledge regarding the functions of riparian vegetation. The fact that many basic parameters in this very simple system model could only be assigned values based on 'informed guesses' provided strong motivation for undertaking the proposed program of research.

6.0 CONCLUSIONS

The model itself is not intended to be adopted as a management tool. At this stage it is only a "game". Even so, it serves as a very powerful tool for explaining the functions of the riparian zone and their interactions to individuals from diverse backgrounds. It also acts as a tool for measuring the ongoing success, or otherwise, of the National Riparian Zone Program. We will continue to use it to evaluate whether or not our experimental efforts have provided useful data, and enhanced our understanding enough to enable accurate predictions of system response.

A full description of the tables and parameter values used in the model, and a Users Manual, is provided in the LWRRDC Project CWA16 Final Report.

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8.0 REFERENCES

Abernathy, B. & Rutherfurd, I.D. (this volume). Cost effective revegetation for channel stabilisation. *Proc. of the First Natl. Conf. on Stream*

Management in Australia, February, 1996. Published by the CRC for Catchment Hydrology.

Bunn, S.E. & Davies, P.M. (1992). Why is the stream fauna of the south-west of Western Australia so impoverished? *Hydrobiologia*. 194: 169-176.

Davies, P. M. (1993). *Ecosystem ecology of upland streams of the northern jarrah forest, Western Australia*. Unpubl. PhD thesis, Department of Zoology, The University of Western Australia. pp 236.

Gippel, C. J., O'Neill, I., & Finlayson, B. (1992). The hydraulic basis of snag management. Melbourne University. Report to the Land and Water Resources Research and Development Corporation.

Grayson, R. B., Doolan, J. M. & Blake, T. (1994). Application of the AEAM (Adaptive Environmental Assessment and Management) to Water Quality in the Latrobe River Catchment. *Journal of Environmental Management, 41*: 245-258.

Hairsine, P. (this volume). Comparing grass filter strips and near-natural riparian forests for buffering intense hillslope pollutant sources. *Proc. of the First Natl. Conf. on Stream Management in Australia*, February, 1996. Published by the CRC for Catchment Hydrology.

Herron, N. (this volume). A review of water flow pathways through the riparian zone. *Proc. of the First Natl. Conf. on Stream Management in Australia*, February, 1996. Published by the CRC for Catchment Hydrology.

Rutherfurd, I.D., Jerie, K. & Wright, M. (1995). Vegetation and Stream Stability: a scale analysis. In *Proc. ASCE First Intl. Conf. on Water Res. Engin.*, San Antonio, Texas, Aug. 1995: 800-809

Quinn, J. M., Cooper, A. B. & Williamson, R. B. (1993). Management of riparian zones and the application of research. pp 53-88 In *Ecology and Management of Riparian Zones in Australia*. Eds (Bunn, S. E., Pusey, B. J. & Price, P.). Published by The Land and Water Resources Research and Development Corporation and the Centre for Catchment and In-stream Research, Griffith University. LWRRDC Occasional Paper Series No 05/93. ISSN 1320-0992.

Wilson, C., Hairsine, P. & Rutherfurd, I. (1995). An Australian perspective on the roles of riparian vegetation in river restoration. In *Proc. ASCE First Intl. Conf. on Water Res. Engin.*, San Antonio, Texas, Aug. 1995.

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

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