Cooperative Research Centre for Coastal Zone, Estuary & Waterway Management

Technical Report 57

Managing riparian lands to improve water quality: optimising nitrate removal via denitrification

Heather Hunter, Christine Fellows, David Rassam, Robert DeHayr, Daniel Pagendam, Carol Conway, Philip Bloesch and Nerida Beard

May 2006

Griffith UNIVERSITY

CSIRO

Queensland Government
Natural Resources, Mines and Water

CRC for Coastal Zone Estuary & Waterway Management

Managing riparian lands to improve water quality: optimising nitrate removal via denitrification

Heather Hunter, Christine Fellows, David Rassam, Robert DeHayr,

Daniel Pagendam, Carol Conway, Philip Bloesch, and Nerida Beard

May 2006

CRC for Coastal Zone
Estuary & Waterway Management

Managing riparian lands to improve water quality: optimising nitrate removal via denitrification

Written by:
Heather Hunter
Christine Fellows
David Rassam
Robert DeHayr
Daniel Pagendam
Carol Conway
Philip Bloesch
Nerida Beard

Published by the Cooperative Research Centre for Coastal Zone, Estuary
and Waterway Management (Coastal CRC)

Indooroopilly Sciences Centre
80 Meiers Road
Indooroopilly Qld 4068
Australia

www.coastal.crc.org.au

National Library of Australia Cataloguing-in-Publication data

Title of the publication: Managing riparian lands to improve water quality: optimising nitrate removal via denitrification

QNRM06110

ISBN 1 921017 18 X (print)

ISBN 1 921017 19 8 (online)

Managing riparian lands to improve water quality: optimising nitrate removal via denitrification

Heather Hunter[1], Christine Fellows[2], David Rassam[3], Robert DeHayr[1], Daniel Pagendam[1], Carol Conway[2], Philip Bloesch[1], and Nerida Beard[2]

[1] Natural Resources, Mines and Water, Queensland

[2] Griffith University

[3] CSIRO Land and Water

Acknowledgments
We wish to acknowledge the valuable contributions made by Kim Markwell and Myriam Raymond; we also thank Rob Frizzo and other landowners for kindly allowing us to conduct the research on their farms. Financial support from the following organisations is gratefully acknowledged: the CRC for Coastal Zone, Estuary and Waterway Management; the CRC for Catchment Hydrology; Land and Water Australia; the Murray-Darling Basin Commission; eWater CRC; the Queensland Government and Griffith University.

Australian Government
Land & Water Australia

COOPERATIVE RESEARCH CENTRE FOR
CATCHMENT HYDROLOGY

eWater CRC

MURRAY-DARLING BASIN COMMISSION

Table of contents

Table of figures

Summary

Managing water quality presents major challenges in freshwater, estuarine and coastal systems in Australia, with problems due to excessive nitrogen levels a priority focus. With appropriate management, riparian buffer zones can reduce the amount of nitrogen reaching waterways from adjacent land-based activities and thereby help protect the water quality of aquatic ecosystems downstream. There is considerable information available on the management of riparian zones to reduce nutrient levels in surface runoff, but relatively little information on reducing levels in sub-surface (groundwater) flows, particularly in Australia. In this paper we present information on sub-surface riparian processes associated with the transport and removal of nitrate (a readily bio-available form of nitrogen), based on results from our research in Australian catchments over the past six years. We also propose guidelines for managing riparian lands to optimise nitrate removal by denitrification, a microbial process by which nitrate is converted to gaseous forms and thus released to the atmosphere. The guidelines aim to: 1) maintain and/or increase organic carbon levels in riparian soils; and 2) assist identification of riparian areas where the duration and extent of saturation are optimal for denitrification to occur, and where greatest reductions in stream nitrate loads are likely to be achieved. Recommendations of existing riparian guidelines, which focus mainly on surface processes are broadly consistent with these aims. In conjunction with the guidelines we present an overview and case study application of the Riparian Nitrogen Model. The model estimates the amount of nitrate removed by denitrification in riparian buffers, taking into account soil properties and other features such as the depth to groundwater, the type of flood event, the slope and width of the riparian zone, and the vegetation type. The model allows users to evaluate the likely impacts of alternative riparian management scenarios on stream nitrate loads and to identify areas to target for rehabilitation.

Introduction

The rehabilitation of riparian zones is a major focus of management strategies now being implemented in Australian catchments to protect and improve water quality and aquatic ecosystem health. Given the large investments being made it is imperative that up-to-date management guidelines are available to support these activities, based on the best-available scientific information. In this paper we focus on guidelines for riparian zone management of nitrogen, as a means of reducing nitrogen levels in nearby streams, rivers and wetlands. The guidelines are based on results from our research in Australian catchments over the last six years.

Aquatic organisms require nutrients for their metabolism, growth and reproduction, but when present in excess, nutrients are considered to be pollutants that can have adverse impacts on aquatic ecosystems. Excesses of nutrients like nitrogen and phosphorus can lead to nuisance growth of algae and other plants, blooms of toxic algae, and to more subtle changes to the species composition and food web structure of aquatic communities (Boulton and Brock, 1999; Schindler, 2006). Recent studies have shown nitrogen to be the key nutrient likely to trigger algal blooms and related problems in multiple aquatic ecosystems in Australia – including coastal systems like Moreton Bay (Dennison and Abal, 1999) and Port Phillip Bay (Murray and Parslow, 1999), and freshwater streams in South-east Queensland (Mosisch *et al.*, 1999 and 2001).

Human activities can greatly increase the quantities of nutrients reaching aquatic ecosystems through applications of fertilisers (in agricultural and urban environments), inputs of nutrients from human and animal wastes (including discharge from sewage treatment plants), increasing the rates of natural processes (like soil erosion) and in some cases increasing the amounts of nutrients in precipitation through inputs of air-borne nutrients (for example, nitrogen-containing emissions associated with burning fossil fuels). There is increasing evidence that excessive nutrient inputs are occurring and degrading rivers, reservoirs, and coastal environments in Australia (for example, Hart and Grace, 2001; Australian State of the Environment Committee, 2001). At the same time, trends in cropping and livestock practices suggest that land use is becoming more intense, with greater use of fertilisers and higher stocking rates (Carpenter *et al.*, 1998). The resulting increases in terrestrial loadings of nutrients present challenges for the management of aquatic environments in these landscapes.

Reducing the sources and off-site movement of nitrogen and other nutrients are the first steps in managing nitrogen loading to streams, but land and vegetation adjacent to streams (riparian zones) can provide a protective buffer between streams and nearby land-based activities. With appropriate management, riparian zones can trap sediment and associated nutrients from surface runoff, thus reducing downstream loadings (Prosser *et al.*, 1999a). In addition, riparian buffers are host to a variety of sub-surface processes that have the potential to transform and remove nitrogen (for example, Cirmo and McDonnell, 1997).

Plants and microbes can take up inorganic forms of nitrogen like nitrate and ammonium, incorporating them into their biomass. The assimilated nitrogen is stored in the biomass of the organism for a variable period of time before it is subsequently decomposed and re-cycled into inorganic forms. Denitrification, the conversion of nitrate to gaseous forms by bacteria, is an important process because unlike assimilation, it effectively removes nitrogen permanently from the ecosystem.

Most of the nitrate is converted to dinitrogen gas (N_2), which occurs naturally as a major constituent of the atmosphere. However, sometimes small amounts of nitrous oxide gas may also be released by denitrification and it is important to keep these to a minimum, since nitrous oxide is a ‘greenhouse gas’ that contributes to global warming. Currently only limited information is available on the factors that promote nitrous oxide emission during denitrification and there is also insufficient information on whether riparian zones are ‘hotspots’ for nitrous oxide compared with other sources (Groffman *et al.*, 1998). The issue serves as a useful reminder that the overall goal of managing the off-site movement of nitrate in catchments should be to minimise the problem at its source and thereby reduce the need for riparian denitrification.

In addition to nitrate, the bacteria that perform denitrification generally require an environment with no oxygen (or very low concentrations) and a source of organic carbon for energy. Riparian zones thus have the potential to support high rates of denitrification because they often have high levels of soil organic carbon and are likely to have shallow water tables and therefore saturated, anaerobic (no oxygen) conditions. Studies in North America, Europe and New Zealand have shown that riparian zones can remove over 90% of the nitrate from the groundwater that flows through them (see review by Hill, 1996).

Relatively little work has been done in Australia, but in three recent projects we have investigated how riparian zones function to reduce nitrate loads in Australian environments[1]. In this paper we use the findings of these three studies to propose guidelines for the management of riparian lands, with the overall goal of increasing the potential for denitrification and thereby reducing the loads of nitrogen entering streams and other surface water bodies. The guidelines focus on:

- Managing soil organic carbon
- Understanding the landscape setting and hydrology to assist identification of riparian areas with the greatest potential for denitrification losses of nitrogen

We also present case studies as examples of how the research findings have informed development of these guidelines. Finally, in recognising that riparian zones perform a variety of functions and therefore their management often has multiple goals, we compare these guidelines for increasing denitrification with existing guidelines that address other riparian functions and processes.

---

[1] The projects, *Nitrogen and carbon dynamics in riparian buffer zones* and *Modelling and managing nitrogen in riparian zones to improve water quality* were jointly funded by the Cooperative Research Centre (CRC) for Coastal Zone, Estuary and Waterway Management and the CRC for Catchment Hydrology; and the project, *In-stream and riparian zone nitrogen dynamics*, was funded by the River Contaminants Program of Land and Water Australia and by the Murray-Darling Basin Commission.

Soil organic carbon and denitrification

Why is this issue important?

Most of the microbes that carry out denitrification require organic carbon as their energy source. Where nitrate is present, greater abundance of organic carbon that can be consumed by microbes (termed bio-available or labile carbon) will typically result in greater removal of nitrate by denitrification.

Management goal – maintain and/or increase soil organic carbon

When soils are saturated and nitrate is present, a good supply of organic carbon will provide the opportunity for that nitrate to be removed via denitrification. Maintaining and/or increasing the amount of organic carbon throughout the soil profile will increase the potential for denitrification to occur, and take into account changing water table levels seasonally and year to year. Organic carbon is particularly important over the depths which are most likely to be intercepted by the water table for long durations (for example, under baseflow conditions).

Achieving the management goal

Much of the organic carbon used by denitrifiers and other microbes is ultimately derived from plants, either over the short term from existing plants, or from past vegetation, which has decomposed and increased the reserves of organic carbon stored in the soil. Management of riparian vegetation and soil can therefore influence the amount of carbon available to support denitrification.

Managing vegetation

Vegetation can add organic carbon to the soil in several ways. Leaves and other litter shed by plants can accumulate on the soil surface. Some of this carbon may reach deeper into the soil profile through leaching, or through burial by deposited sediments. Plant roots extend deeper into the soil profile, and may exude carbon compounds while living, but also provide a good source of organic carbon as they die and decompose.

Generally, the density of vegetation will roughly correspond to the amount of organic carbon provided through litter and roots, but the characteristics of individual plants should also be taken into account. Both re-vegetation and selective planting into existing vegetation can serve to increase soil organic carbon levels where riparian condition is poor. A mixture of plants with different rooting densities and depths should help maintain or increase soil organic carbon levels throughout the soil profile. A mix of plant species can also provide a range of litter types with varying rates of decomposition, thus providing a ‘slow release’ organic carbon supply for the short and longer term. Trees, shrubs and grasses can all play a useful role and a combination of these vegetation types may often prove ideal. Since the overall goal is to reduce dissolved nitrogen levels to improve in-stream water quality, planting of nitrogen fixing species should probably be avoided in riparian areas where possible, since they can add nitrogen to the soil. However, this may not be practical depending on the environment, because many natural pioneers are nitrogen fixing (i.e. wattles).

Minimising soil disturbance and clearing

While increasing vegetative cover serves to increase soil organic carbon, conversely, clearing riparian vegetation can deplete carbon levels. Removing the vegetation removes the source of organic carbon, and as existing stocks decompose and are used by the microbial community, no new carbon enters the system. Furthermore, the breakdown of existing soil carbon reserves can be accelerated due to the soil disturbance that often accompanies clearing. Cultivation can similarly increase the rate of organic carbon breakdown in soil.

Although it may take many years to build up significant reserves of organic carbon in soils, they can be depleted quite rapidly if not managed carefully. Where selective removal of riparian vegetation is necessary (for example, for weed removal or timber harvesting) the timing, location and method of removal should be managed to minimise soil disturbance and maintain as much vegetative cover as possible. This will also help minimise the risk of increasing sediment levels in surface runoff.

Case study: Measuring the denitrification potential of riparian soils

To explore the factors that influence denitrification in riparian soils, we measured rates of denitrification potential at many locations around South-east Queensland, as well as locations in Victoria and Western Australia. One common finding across these very different environments is that rates of denitrification potential are highest near the soil surface and decrease with depth. We also see the same general pattern with soil organic carbon content, with the highest values near the surface. This is evident in Figure 1 below, which shows rates of denitrification and organic carbon content for three depth intervals in riparian soils from Coochin Creek in South-east Queensland.

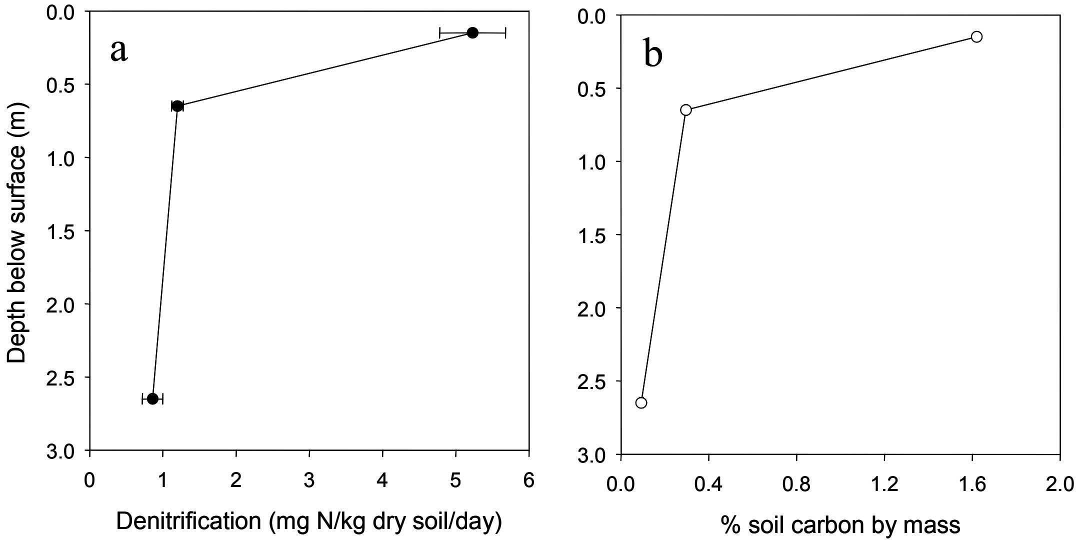

Figure 1: a) Denitrification potential and b) organic carbon content of riparian soils from three depths (0 – 0.3 m, 0.3 – 1.0 m, and 1.8 – 3.5 m) at Coochin Creek, South-east Qld. Points represent the mean and standard error from three replicates (values of SE for carbon data are smaller than the size of the symbols). Rates of denitrification potential were measured on day 2 of an 11-day experiment (described below).

To see if rates of denitrification change with time following saturation, we incubated riparian soils in the laboratory for 11 days. Rates of denitrification and the amount of nitrate remaining were measured periodically in soils taken from three depths. Nitrate was added to the incubations to raise the concentration by 8 mg N/L nitrate, a concentration comparable to the high end of the range of concentrations observed in groundwater at the site. We found that rates of denitrification were much higher in the shallow soil than the medium or deep, but decreased quickly as the nitrate was consumed. For all three soil depths, we observed maximum rates of denitrification after 2 days of incubation, although medium and deep soils had fairly consistent rates across the duration of the experiment (Figure 2a). All three soils appeared to contain sufficient carbon to completely remove all nitrate via denitrification, although the experiment was not continued for long enough to confirm this for the medium and deep soils (Figure 2b). In a separate short-term incubation experiment, denitrification potential was assessed in soils of differing organic carbon content: rates of denitrification were shown to increase with increasing soil carbon content and rates generally increased substantially with the addition of bio-available carbon (Beard *et al.*, 2003).

In comparing riparian soils from contrasting geographic areas, we observed similar rates of denitrification potential, although rates were lower at some sites in Western Australia (Figure 3). Soils from these Western Australian sites tended to have higher sand and lower organic carbon contents, which likely contributed to the lower denitrification rates. Rate measurements were performed at a constant laboratory temperature (22°C), removing the potential influence of temperature when comparing soils from different regions. For shallow soil depths (0-.03 m, Figure 3) there were no consistent differences in denitrification potential between riparian zones with and without dense tree cover, suggesting that grass and herbaceous cover can be as effective as trees in providing organic carbon to support denitrification.

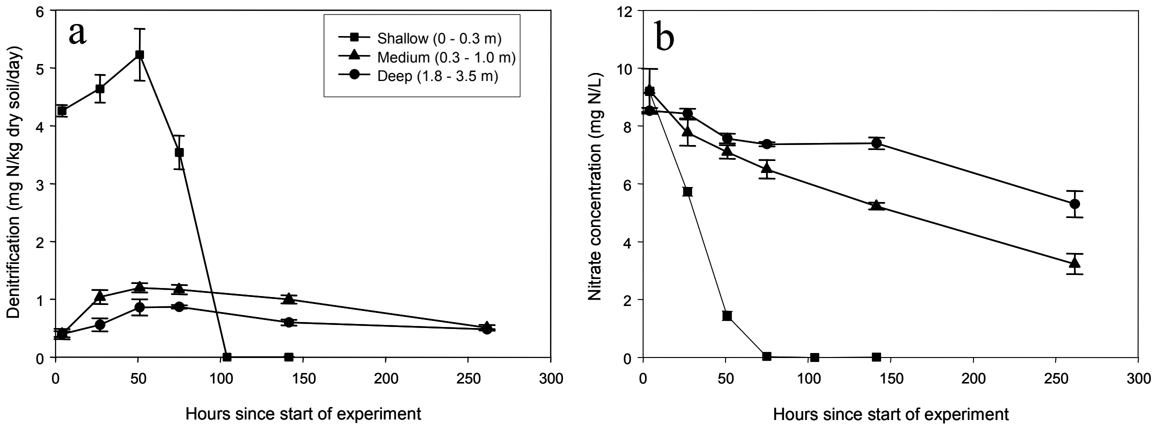

Figure 2: Differences over 11 days in a) denitrification rate, and b) nitrate depletion during incubation of shallow, medium and deep riparian soils. Points represent the mean and standard error from three replicates.

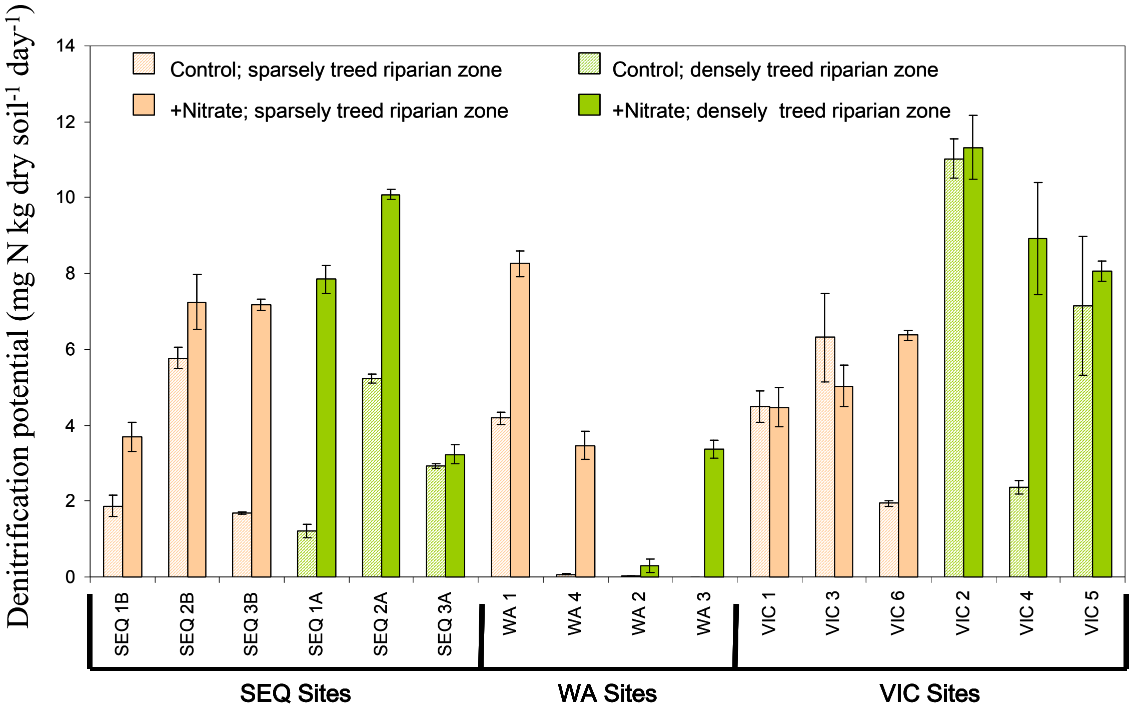

Figure 3: Denitrification potential of shallow riparian soils from three different regions. Values are the mean and standard error of three replicates. Soils either received no additional nitrate (control) or received nitrate to increase the concentration by 3 mg N/L (+ nitrate).

Landscape setting and hydrology

Why is this issue important?

The landscape setting and hydrology are critical in determining the extent of riparian denitrification for the following reasons:

- Typically, saturated soils provide the anaerobic soil conditions required for denitrification and hence the importance of hydrology.
- The position of the groundwater table relative to the root zone and the stream channel form affect the overall potential for denitrification, as organic carbon availability usually increases towards the soil surface. Riparian buffers that are relatively low in the landscape are more likely to have shallow groundwater tables.
- The slope of the riparian buffer affects the extent of denitrification, with flat buffers providing a greater opportunity for both groundwater and surface water to interact with the carbon-rich root zone and hence enhance denitrification.
- The hydraulic conductivity of riparian soils, the residence time and volume of groundwater interacting with the buffer, and the water table level all affect the extent of denitrification. Low hydraulic conductivity soils can sustain a shallow water table that allows for contact with the more active shallow sediments and prolonged residence time, but very low-conductivity soils can impede flow altogether (Rassam, 2005a).

Management goal – identify areas with optimal potential for denitrification

Not all riparian zones within a catchment have a suitable landscape setting and hydrology for denitrification to be important. Similarly, not all riparian zones may be exposed to the same loads of nitrate coming from their catchment. Thus, riparian rehabilitation or protection activities aimed at reducing stream nitrogen loads should focus on areas with the greatest denitrification potential. Emphasis should be placed on optimising denitrification in small-to-medium sized streams, which typically account for about three-quarters of the total stream length within a catchment (Prosser *et al.* 1999b).

Achieving the management goal

Identifying areas with optimal duration and extent of saturation

In many situations the hydrology and landscape setting are givens that cannot be changed and the management goal in these situations is to identify areas where conditions are most likely to be conducive to denitrification. This involves:

- Understanding both the surface and sub-surface (groundwater) hydrology
  - When surface water is temporarily stored in stream banks or riparian zones during storm events there is an opportunity for denitrification to remove nitrate before the water drains back to the stream. The frequency and magnitude of flood peaks dictate the extent of interaction with the riparian sediments (Rassam *et al.*, 2006)
  - Sub-surface flow rates and residence times are controlled by local hydraulic gradients; the closer the groundwater table to carbon-rich soil beneath riparian vegetation, the greater the potential for denitrification
  - Soil attributes such as hydraulic conductivity may indicate areas where the hydrology is likely to be suitable for denitrification processes.
- Understanding the landscape setting – the duration and extent of saturation are likely to be optimal in riparian buffers with the following characteristics
  - low in the landscape
  - flat
  - relatively shallow stream banks
  - soil of moderate hydraulic conductivity (Rassam, 2005)
  - These landscape features may be identified with the aid of a digital elevation model (DEM) – for example, a DEM can be used to calculate riparian buffer slope and to derive indices of wet areas in the landscape.

While it was not a focus of our research, it is worth noting that human modification of catchments such as channelisation, land drainage, and water abstraction may reduce both the spatial extent and duration of riparian soil saturation, decreasing the opportunity for denitrification to occur (Pinay *et al.*, 2002; Burt and Pinay, 2005). In some situations it may be possible to alter these modifications and so change the dynamics of saturation. Additionally, in regulated systems there may be opportunities to increase the extent and duration of riparian zone saturation through controlled releases of water (for example, environmental flow releases in the Barmah Forest, River Murray).

Assessing potential nitrate loads coming from the catchment

Catchment land use provides an indication of potential nitrate loads. For example, higher loads are more common in areas where fertilisers are widely used, livestock numbers are high, or residential development is non-sewered – thus highlighting these areas as priorities for riparian rehabilitation.

The Riparian Nitrogen Model

The factors affecting denitrification potential are complex and interactive, thus making it difficult to evaluate riparian buffers based on observation alone. Using results from our experimental research, we have developed a modelling tool, the Riparian Nitrogen Model (RNM), which allows the user to assess these factors holistically and so identify areas to target for riparian rehabilitation and/or protection.

Conceptual models for denitrification

The RNM includes three conceptual models for riparian zone denitrification. For low-order, ephemeral streams , the surface (stream) water is likely to interact with the carbon-rich root zone of a riparian buffer in areas where a localised perched shallow groundwater table can form – this happens when a low-conductivity confining layer underlies the permeable soil of the floodplain (Figure 4).

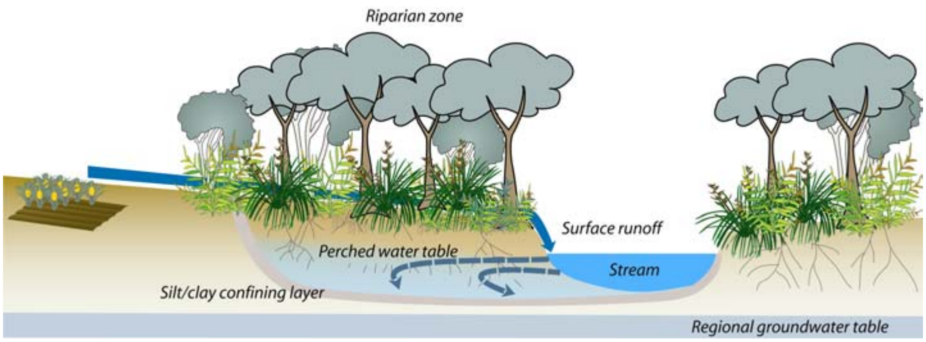

Figure 4: Surface water interaction with riparian buffers in ephemeral streams

Denitrification in riparian zones of perennial streams primarily occurs via two mechanisms – firstly, while baseflow passes though the riparian zone; and secondly, as stream water is stored in banks when a flood wave passes. Denitrification is assumed to occur only in the saturated part of the root zone across the width of vegetated riparian buffers.

The first mechanism (Figure 5) involves the entire baseflow component of flow obtained from a catchment rainfall-runoff model. The extent of interaction between baseflow and the saturated part of the root zone determines the amount of denitrification that takes place (this is a function of root zone depth and depth to the water table).

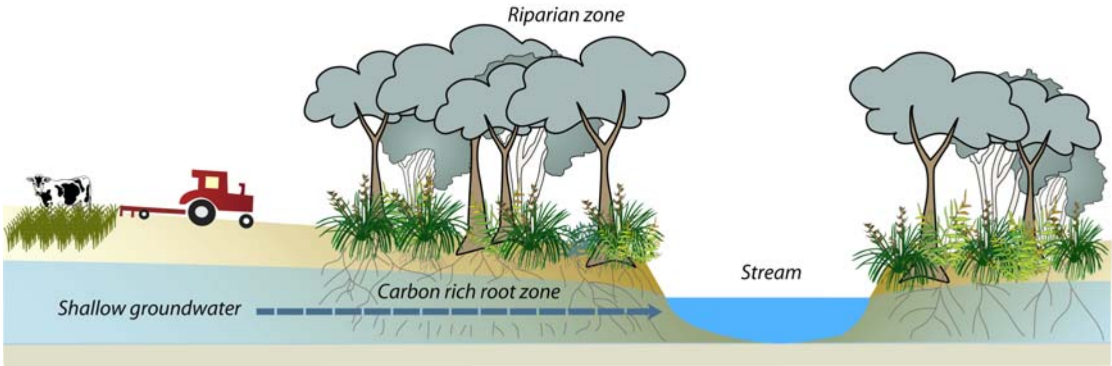

Figure 5: Groundwater interaction with riparian buffers in perennial streams: baseflow component

The second mechanism in perennial streams involves that part of the stream flow that is stored in stream banks as a flood wave passes (termed bank storage). This is similar to the concept of lateral flow described previously for ephemeral streams – that is, surface water temporarily becomes groundwater, nitrate is removed and the water then drains back to the surface water system (Figure 6). The volume of water stored depends on the width of the floodplain and its slope, the soil's specific yield, and the volume of the flood event.

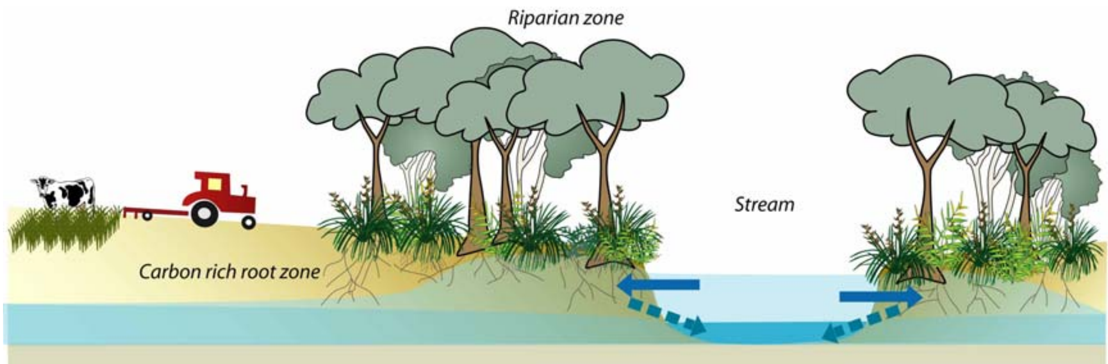

Figure 6: Surface water interaction with riparian buffers in perennial streams: bank storage during flood events

Overview of the Riparian Nitrogen Model

The RNM estimates the potential for nitrate removal via denitrification (Rassam *et al.*, 2005a). It is most suitably applied in riparian buffers belonging to low- and middle-order streams. The RNM estimates the mass of nitrate removed in riparian buffers according to the three conceptual models described above. The estimates of nitrate removal vary with the depth to groundwater, the flood event size and duration, the slope and width of the riparian zone, the vegetation type (relative rooting depth) and soil properties including denitrification potential. The estimates are made at a sub-catchment scale and are not spatially explicit for individual stream reaches.

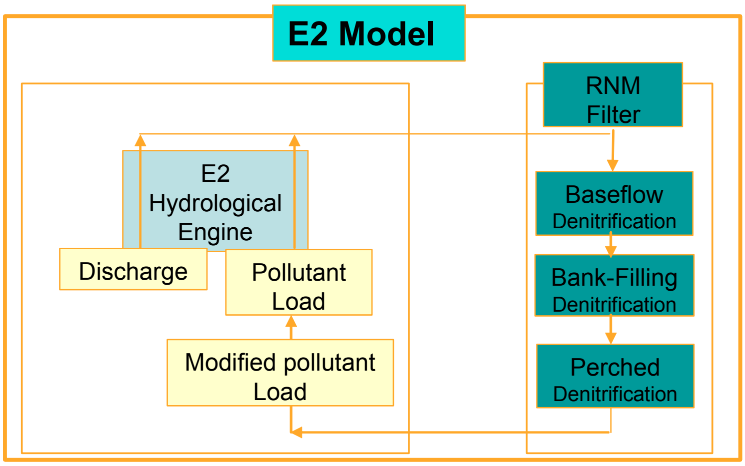

Figure 7: Example showing the RNM as a filter module within the catchment-scale water quality model, E2 (for more details on E2, see http://www.toolkit.net.au/).

The RNM operates as a filter (plug-in) module within a catchment-scale model (for example, Figure 7) or as a stand-alone package. It calculates the amount of nitrate removed by the three hydrological processes (baseflow, bank-filling and perched watertable), based on estimates for each of the volume of water, its riparian/bank residence time, and the average denitrification rate in the saturated root zone.

At a finer scale, the mapping tool (in the stand-alone version of the RNM) can provide ratings of the 'Rehabilitation Index' (RI), which can be used to target specific stream reaches for rehabilitation (Rassam *et al.*, 2005a; Rassam and Pagendam, 2006). The RI couples spatial information on the likelihood of nitrate contamination (based on land use) with the potential for its removal (based on denitrification potential). The maps produced show the RI of riparian zones along the stream network, which can be used to identify areas most likely to provide optimal benefits from riparian rehabilitation – for example, poorly vegetated, low lying riparian areas in agricultural catchments. Follow-up field investigations are recommended to inspect areas identified in the RI maps to confirm their potential for nitrate reduction. Note also that this assessment of priorities is based purely on biophysical factors – further evaluation is needed in planning riparian rehabilitation activities to take into account the associated social and economic factors that may affect the feasibility of the works proposed.

Case study: Applying the Riparian Nitrogen Model in the Maroochy catchment

Identifying riparian areas to target for rehabilitation in the Maroochy catchment

Using the catchment model E2, we tested the RNM in the Maroochy River catchment and assessed the potential for riparian rehabilitation to reduce stream nitrogen loads (Rassam *et al.*, 2005b). The Maroochy catchment covers an area of around 600 km^2 in South-east Queensland; around 20% of the catchment is covered with native vegetation and the rest is extensively used for agriculture and urban development. The catchment has a coastal, sub-tropical climate, with an annual rainfall of about 1 700 mm per year. For each sub-catchment, we modelled the generation of runoff, baseflow and nitrate and the removal of nitrate in riparian zones by denitrification.

To assess the potential impact of riparian zone management in the Maroochy sub-catchments, we compared sub-catchment nitrate loads for a modelled scenario with fully vegetated riparian buffers, to a scenario where there were no riparian buffers. This showed that for the denitrification rates we used in this study, the riparian buffers have the capacity to remove around 5–20% of the annual nitrate load of each sub-catchment.

We also assessed the effects on nitrate removal of scenarios in which we varied either the rooting depth of riparian vegetation or the width of riparian buffers. According to the RNM conceptualisation, increasing rooting depth (for example, having trees rather than shrubs) extends the active zone where denitrification can potentially occur and thus increases the chances of a deeper groundwater table intercepting this zone. For the Maroochy catchment, the modelling results indicate that the optimum rooting depth is 2–3 metres (deeper roots marginally increase nitrate removal).

Similarly, a wider riparian buffer provides a longer residence time thus increasing the overall denitrification potential (for the baseflow component); it also means there is a larger volume of stream water interacting with riparian sediment during flood events (for the bank storage component). Model results for the Maroochy sub-catchments indicate that increasing the riparian buffer width beyond 10 m only marginally increases nitrate removal.

By applying the mapping tool of Rassam and Pagendam (2006) we were able to zoom in on each sub-catchment to identify specific stream reaches with the highest RI – that is, the areas where riparian rehabilitation would most likely yield the greatest reduction in stream nitrate loads (red stream reaches in Figure 8).

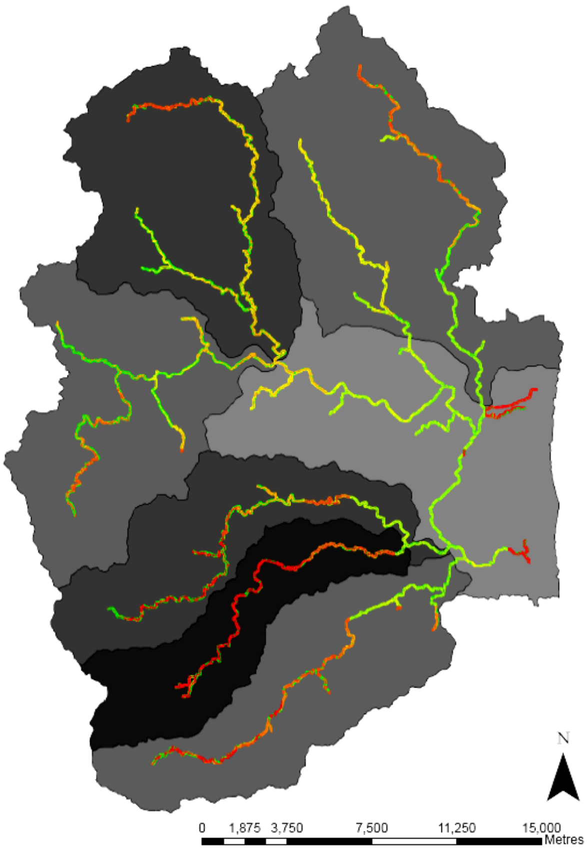

Figure 8: Output of the Riparian Mapping Tool showing the Rehabilitation Index for the Maroochy catchment; stream reaches shown in red have the highest potential for rehabilitation to reduce stream nitrate loads (potential decreases from red to yellow to green). Sub-catchments are shaded to indicate their aggregated potential (decreasing from black through to light grey).

Guidelines for optimising nitrate removal

In the preceding sections we have outlined the many factors to consider in assessing the importance of riparian zone management for reducing stream nitrate loads in a catchment, and have also given an overview of the RNM model that can assist this process. Based on this information we propose the following management guidelines (Table 1) that focus on optimising the denitrification potential of riparian lands.

Table 1: Guidelines for management of riparian lands to optimise their denitrification potential

Focus	Management Approach
Protect and/or increase levels of bio-available organic carbon in riparian soils, including those at depth	• Maintain a mix of vegetation types (trees, shrubs and grasses), species and ages, to provide a range of: - rooting depths and rooting densities - litter types - decomposition rates • Minimise soil disturbance, e.g., due to: - livestock - vehicles - weed removal - re-vegetation • The required buffer width and depth of rooting differs in each situation and depends on factors such as the landscape setting, hydrology and soil type. The Riparian Nitrogen Model can assist in defining the optimal buffer width and depth for specific sub-catchments. In the interim, the values we derived for the Maroochy catchment (width ≥ 5-10 m; rooting depth ≥ 2-3 m) may provide an indicative guide; note also that this buffer width is consistent with those proposed by existing guidelines (Table 2).
Identify riparian areas to target for rehabilitation	• Identify areas with optimal duration and extent of saturation: - low lying - relatively flat - low stream banks - soils of moderate hydraulic conductivity • Assess the potential diffuse sources of nitrate in the catchment. For example, higher loads can be expected from areas with the following land management practices, compared with less developed parts of a catchment: - extensive use of nitrogen fertilisers - intensive livestock production - use of septic systems in residential areas • Assess the type and condition of existing vegetation in areas that meet the above criteria and determine the relative gains in denitrification potential likely to be achieved by their rehabilitation • By assessing all of the above factors holistically, the Riparian Nitrogen Model can indicate the sub-catchments where riparian rehabilitation is likely to yield the greatest reductions in stream nitrate loads. It can also highlight stream reaches within these sub-catchments where groundwater discharge of nitrate is most likely to occur.

Comparison with existing management guidelines

The primary focus of riparian zone management to date has been on surface processes and functions that are influenced by vegetation – including reducing bank and stream erosion; trapping nutrients and sediments; maintaining in-stream ecological function (by providing shade and inputs of organic matter); and providing habitat and food for native organisms. Similarly, management guidelines have focused on aspects of riparian vegetation that influence these surface processes, such as vegetation density, location and species composition. The sub-surface benefits of riparian zones are now being recognised, but to date there have been few science-based guidelines specific to these issues. In instances where sub-surface processes are considered, the guidelines are typically less well developed than those for surface processes.

In our review of existing riparian zone management guidelines for Australia and New Zealand, we found two comprehensive documents; *Riparian Land Management Technical Guidelines, Volumes 1 and 2*, published by Land and Water Australia[2] and *Managing Riparian Zones, Volume 2: Guidelines*, published by the Department of Conservation, Te Papa Atawhai[3]. We evaluated these two sets of guidelines from our perspective of sub-surface processes for optimising nitrate removal via denitrification. The aims and recommendations of these current guidelines are summarised below (Table 2), along with our additional comments outlining the sub-surface benefits likely to be associated with these current guidelines.

In most cases we consider that the current recommendations for enhancing surface processes (Table 2) would be likely to maintain or enhance soil organic carbon, meeting the first of our management goals. These recommendations also provide some general guidance on selecting riparian areas most likely to assist in nitrate reduction via sub-surface processes and these are consistent with the guidelines we propose (Table 1). Both the current and new guidelines deal primarily with the assumption that hydrologic conditions will remain unchanged, but as noted earlier there is sometimes the potential to change the dynamics of saturation to optimise denitrification.

---

[2] Lovett and Price (editors) 1999a and 1999b
[3] Collier *et al.*, 1995

Table 2: Current guidelines for riparian management and their associated sub-surface benefits related to increasing denitrification potential

Focus	Guideline[1]	Sub-surface Benefits
Stream and bank stability	• Stagger planting along the top bank as well as on the bank face and near-stream • Diverse root systems are needed to cover a range of erosion processes: - deep and extensive root systems - dense network of medium to small roots to reinforce upper soil • Use a range of native plants	• Provides a source of organic carbon in all of these areas • Differing root depths can provide a source of organic carbon throughout the soil profile • Different plants have different decay rates and provide a range of sources of organic carbon
Reduce contaminants in overland flow	• Riparian width should be 10 m or more from the top of the bank • If riparian land has a steep gradient, a 5 m dense grass buffer zone should be established at the outer edge of the riparian zone	• Provides organic carbon in this area • Slows down surface flow and increases infiltration into the soil and groundwater
Light and Temperature	• 75% cover is needed for control of light and temperature • Although target cover can be achieved with a singe line of trees, width should be over 10 m for other factors (micro-climate etc.) • Use native trees which are wide compared to their height, have high shade indices and can grow out over the stream	• Overall these guidelines provide increased organic carbon in the soil as a result of leaf litter breakdown and roots
Managing inputs of terrestrial carbon	• Plant low, overhanging vegetation (provides terrestrial invertebrates and leaf litter) • To ensure a regular and diverse supply of terrestrial carbon plant a range of native vegetation with: - differing decay rates - differing sizes - differing growth rates	• Provides stream organic matter • Provides an organic matter source (leaf litter, roots) throughout the soil profiles and over time. Young, actively growing vegetation can take up and store nitrate, while older trees produce more abundant organic carbon from litter (root and leaf decay).
Terrestrial Habitat	• Plant a range of native species at mixed densities and combinations • Plant native species that provide differing food and habitat sources • Plant native species with a variety of different life forms (shrubs and groundcover as well as trees) • Plant both long and short-lived trees (aim to have a mosaic of plant communities at different stages of development) • Maximise riparian area (50-300 m wide) as well as links to other riparian lands and bushland • Undertake pest control and control stock access	• Provides a mixture of organic carbon types in different areas • Provides a range of organic carbon types, well-distributed through the soil profile (from different rooting depths) • Provides a continuous supply of organic carbon over time (also see above *re.* younger *vs.* older vegetation) • Greater potential for organic carbon to accumulate • Minimise disturbance of soil
Reduce groundwater flow of contaminants	• Areas of concern (probable groundwater and nitrate input) should be planted with trees or deep-rooted perennial grasses • Plant riparian vegetation in areas of low relief and low gradients (slow groundwater flow) • Plant riparian vegetation in areas which experience seasonal saturation • Width should be 10 m from the top of the bank (buffers up to 50-100 m wide may be required in areas of fast flowing groundwater)	• Consistent with our research findings and guidelines (Table 1)

[1] Adapted from Collier *et al.* (1995) & Lovett and Price (1999b).

Conclusions

Results of these studies confirm that riparian buffers can play a significant part in reducing the loads of nitrate entering waterways in Australian catchments. The research has identified the key factors and sub-surface processes involved and this information has been used as a basis for providing practical guidelines for riparian zone management. The guidelines focus on achieving optimal removal of nitrate via denitrification in those riparian lands where sub-surface processes are likely to be important. They concentrate on maintaining and/or increasing organic carbon levels in riparian soils; and identifying areas where the duration and extent of saturation are optimal for denitrification to occur. Recommendations of existing guidelines for riparian management are broadly supportive of these aims.

Data and information from the research have also been used to develop a model (the RNM) which can be used to support planning processes for riparian rehabilitation, by providing estimates of sub-catchment nitrate loads and the likely changes in loads that may be achieved with different riparian management scenarios. In addition, the RNM can indicate the riparian areas within a sub-catchment that are likely to yield the greatest nitrate reduction, thus assisting users to set priorities for their rehabilitation activities. The case study application of the RNM in the Maroochy catchment presented in this paper indicates the potential utility of the RNM as a tool to support land and water managers in their decision-making processes.

More work is required to further test and refine the RNM and to link it to other models and processes for evaluating social and economic considerations that may be associated with these decisions. Further investigations into the factors underlying the denitrification potential of riparian soils would yield additional insights into the processes involved and allow the management guidelines to be enhanced. Similarly, research into the rooting patterns of different plant species and the quantity and quality of organic carbon they contribute to riparian soils would enable the guidelines to provide more specific information on suitable species to plant for optimal denitrification.

References

Australian State of the Environment Committee. 2001. *Australia State of the Environment 2001*, Independent Report to the Commonwealth Minister for the Environment and Heritage, CSIRO Publishing on behalf of the Department of the Environment and Heritage, Canberra.

Beard, N.J., Fellows, C.S., Hunter, R.H., Rassam, D., DeHayr, R., and Bloesch, P. 2003. Denitrification potential of aquifer sediments in a southeast Queensland riparian zone Proceedings of the 1st National Integrated Catchment Management Conference, 26-28 November, Parramatta, Australia, paper T04:04.

Boulton, A.J., and Brock, M.A. 1999. *Australian Freshwater Ecology: Processes and Management*. Gleneagles Publ., Glen Osmond, SA, Australia, 300 p.

Burt, T.P., and Pinay, G. 2005. Linking hydrology and biogeochemistry in complex landscapes. *Progress in Physical Geography* **29,** 297-316.

Cirmo, C.P., and McDonnell, J.J. 1997. Linking the hydrologic and biogeochemical controls of nitrogen transport in near-stream zones of temperate-forested catchments: a review. *Journal of Hydrology* **199**, 88-120.

Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, R.W., Sharpley, A.N., and Smith, V. H. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications **8**:559-568.

Collier, K.J, Cooper, A.B., Davies-Colley, R.J., Rutherford, J.C., Smith, C.M., and Williamson, R.B. 1995. *Managing Riparian Zones: A contribution to protecting New Zealand's rivers and streams. Volume 2: Guidelines*. Department of Conservation, Wellington, New Zealand.

Dennison, W.C., and Abal, E.G. 1999. *Moreton Bay Study.* SEQRWQMS ISBN 0 9586368 1 8, 245 p.

Groffman, P.M., Gold, A.J., and Jacinthe, P.-A. 1998. Nitrous oxide production in riparian zones and groundwater. *Nutrient Cycling in Agroecosystems* **52**, 179-186.

Hart, B.T., and Grace, M.R. (eds.) 2001. *Nitrogen Workshop 2000: Sources, Transformations, Effects and Management of Nitrogen in Freshwater Ecosystems*. . Occasional Paper 10/00. Land and Water Australia, Canberra, ACT, 133 p.

Hill, A. R. 1996. Nitrate removal in stream riparian zones. Journal of Environmental Quality **25**:743-755.

Lovett, S., and Price, P. (eds.) 1999a. *Riparian Land Management Technical Guideline. Volume 1: Principles of Sound Management.* Land and Water Resources Research and Development, Canberra, ACT.

Lovett, S. and Price, P. (eds.) 1999b. *Riparian Land Management Technical Guideline. Volume 2: On-ground Management Tools and Techniques*. Land and Water Resources Research and Development, Canberra, ACT.

Mosisch, T., Bunn, S.E., Davies, P.M. and Marshall, C.J. 1999. Effects of shade and nutrient manipulation on periphyton growth in a small subtropical stream. *Aquatic Botany* **64**, 167-177.

Mosisch, T.D., Bunn, S. E., and Davies, P.M. 2001. The relative importance of shading and nutrients on algal production in subtropical streams. Freshwater Biology **46**, 1269-1278.

Murray, A.G., and Parslow, J.S. 1999. Modelling of nutrient impacts in Port Phillip Bay – a semi-enclosed marine Australian ecosystem. *Mar. Freshwater Res.* **50**, 597-611.

Pinay, G., Clement, J.C., and Naiman, R.J. 2002. Basic principles and ecological consequences of changing water regimes on nitrogen cycling in fluvial systems. *Environmental Management* **30,** 481-491.

Prosser, I., Bunn, S., Mosisch, T., Ogden, R., and Karssies, L. 1999a. The delivery of sediment and nutrients to streams. In, *Riparian Land Management Technical Guideline. Volume 1: Principles of Sound Management*, Lovett, S. and Price, P. (eds.). Land and Water Resources Research and Development, Canberra, ACT, pp. A:37-A:60.

Prosser, I., Ogden, R., and Bunn, S. 1999b. The influence of space and time. In, *Riparian Land Management Technical Guideline. Volume 1: Principles of Sound Management*, Lovett, S. and Price, P. (eds.). Land and Water Resources Research and Development, Canberra, ACT, pp. A:9-A:16.

Rassam, D.W., Pagendam, D., and Hunter, H. 2005a. The Riparian Nitrogen Model: basic theory and conceptualisation, CRC for Catchment Hydrology Technical Report, 05/9, 38 p.

Rassam, D.W., Pagendam, D., and Hunter, H. 2005b. Implementing the Riparian Nitrogen Model to assess the role of riparian buffers in the Maroochy Catchment. The International Congress on Modelling and Simulation, December 12-15, Melbourne, Australia, pp. 1444-1450.

Rassam, D.W., Fellows, C., DeHayr, R., Hunter, H., and Bloesch, P. 2006. The hydrology of riparian buffer zones; two case studies in an ephemeral and a perennial stream. *Journal of Hydrology*, In Press.

Rassam, D.W., and Pagendam, D., 2006. A mapping tool to prioritise riparian rehabilitation in catchments. MODFLOW and More 2006: Managing Ground-Water Systems, Golden, Colorado USA, May 22-24.

Rassam, D.W., 2005. Impacts of hillslope-floodplain characteristics on groundwater dynamics: Implications for riparian denitrification. The International Congress on Modelling and Simulation, December 12-15, Melbourne, Australia, pp. 2735-2741.

Schindler, D.W. 2006. Recent advances in understanding and management of eutrophication. *Limnology and Oceanography* **51**, 356-363.