Stream-side studies focus on improving waterway health

Beneath the ribbons of vegetation that hug the contours of rivers, creeks and streams, lives a microscopic world churning with the intensity of a human city. Here competition for food is fierce, but members of this microbial metropolis can perform a range of complex chemical tasks that allow them to make the most of the nutrients available, and maintain healthy 'riparian' (near–stream) and aquatic ecosystems.


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One of these chemical tasks, undertaken by specialised soil bacteria, is the removal of nitrogen, in the form of nitrate, from the riparian environment. This process, known as 'denitrification', transforms nitrate into nitrogen gas, which is then released into the atmosphere.

Studies in North America, Europe and New Zealand have shown that riparian zones – the narrow strips of vegetation and soil flanking a watercourse – can remove over 90% of the nitrate from the groundwater that flows through them.

A recent study in south-east Queensland has shown that riparian zones can play an important role in reducing the amount of nitrate flowing into waterways. This can help protect downstream aquatic ecosystems and lessen the risk of problems such as algal blooms occurring. Information obtained from the study is helping to define management practices that can enhance the ability of riparian zones to remove nitrate. When incorporated into catchment water quality models, information from the study will allow users to assess the impacts of various riparian management options on downstream water quality. The models will also enable users to identify priority areas where riparian management activities can be most effective in removing nitrate.


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Coastal CRC
COOPERATIVE RESEARCH CENTRE FOR CATCHMENT HYDROLOGY
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Some of this nitrate, which comes from fertilisers, sewage, or the breakdown of organic matter, is taken up by riparian vegetation or assimilated into microbial cell proteins. But a significant proportion is permanently removed from the riparian environment through denitrification. As aquatic plants thrive on excess nitrate, denitrification is important in reducing the occurrence of undesirable algal blooms.

These overseas findings raise questions about the importance of soil processes, and especially denitrification, in Australian riparian systems. Do they play a similar role in reducing nitrate loads in streams, and if so, could denitrification be optimised by improving riparian zone characteristics through better management?

Answers for Australia

Answers to these questions are essential if we are to evaluate all options for improving the health of our waterways. In south–east Queensland, for example, the flow of nitrate-rich groundwater and surface runoff from agricultural and urban areas may have been increasing the risk of algal blooms in coastal and freshwater systems. In 2001, a catchment–wide survey of stream water quality in the Sunshine Coast hinterland, revealed nitrate concentrations up to 60 times higher than the guideline value recommended for protection of aquatic ecosystems in lowland sub–tropical streams (0.06 mg/L nitrogen as nitrate).

Adopting the concepts and management strategies developed by other countries to our riparian zones may not be appropriate, given our different climate, geology, flow regimes and farming systems. So scientists from the Department of Natural Resources and Mines and Griffith University have taken the first steps towards understanding subsurface riparian zone processes in an Australian context. Their research is jointly supported by the Cooperative Research Centre (CRC) for Coastal Zone, Estuary and Waterway Management and the CRC for Catchment Hydrology.

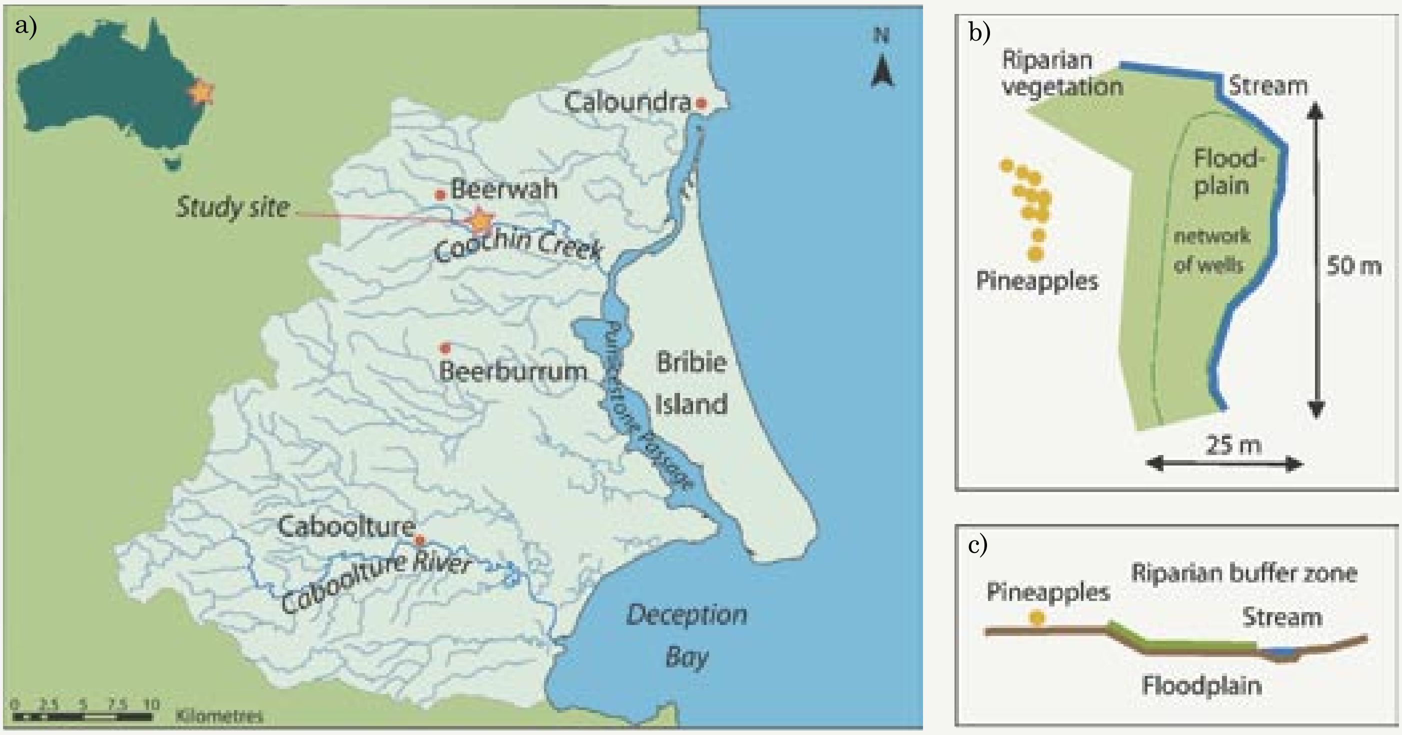

Figure 1. a) Map showing location of study site near Coochin Creek in SE Queensland; **b) & c)** schematics of the study site on a small ephemeral tributary of Coochin Creek.

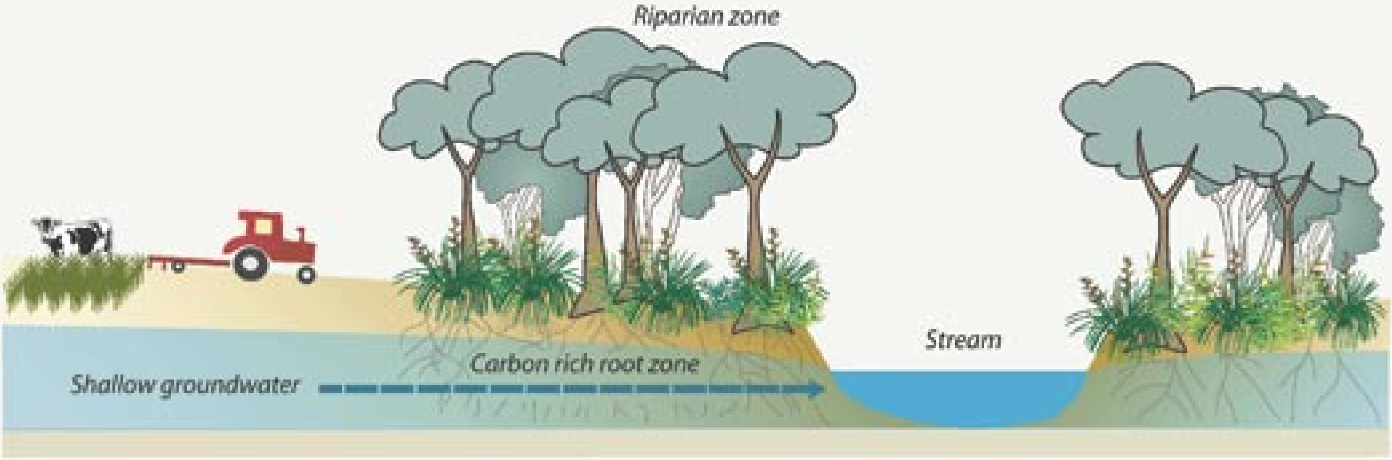

Figure 2. Conceptual model showing the movement of shallow groundwater from beneath an agricultural field (a potential source of nitrate) through carbon–rich riparian soils to a stream.

Denitrification drivers

Riparian zones of relatively small streams are the prime focus for management. Collectively, the networks of these small streams in catchments receive most of the direct drainage from surrounding land areas and thus contribute most of the flow for larger stream channels further downstream.

In 2000, the team commenced a project – Nitrogen and Carbon dynamics in riparian buffer zones – near Coochin Creek on Queensland's Sunshine Coast. This perennial stream and its associated tributaries form part of the Pumicestone Passage catchment (Figure 1) that drains into Moreton Bay.

The research site – located on a pineapple farm near the creek – was selected because of its healthy riparian vegetation. The site also fulfilled the requirements of the team's conceptual model, which emphasised the presence of three key drivers of denitrification. These were: a high organic carbon content in the soil; the potential for anaerobic conditions (no oxygen); and the potential for a flow of shallow, slow–moving groundwater through the riparian zone towards the stream (Figure 2). These conditions favour denitrification for a number of reasons.

Firstly, the bacteria that convert nitrate to nitrogen gas do so only in the absence of oxygen. They won't get far, however, without organic carbon from the soil, leaves, roots and other vegetation common to healthy riparian zones, to supply their energy needs. Finally, a shallow groundwater table is needed to bring nitrate from surrounding areas into the denitrification hotspot, and to maintain waterlogged and therefore anaerobic conditions.

Analysis of soil cores taken from the riparian zone of the ephemeral stream near Coochin Creek, showed organic carbon concentrations of up to 4.5% in the surface layers – probably enough to support denitrification, and considerably more than was found in soils of the nearby agricultural fields.

But what of the groundwater dynamics or 'hydrology'? Was groundwater directed through the riparian zone, and was it suitably slow, shallow and capable of maintaining anaerobic conditions?


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Site hydrology

To investigate further, the team sank a number of wells at different depths within a 50 m stretch of riparian zone, beside the ephemeral stream. Pressure transducers that continuously recorded water table heights were then installed in the wells (Figure 3). Readings from these pressure transducers identified two separate water tables; a localised system lying above a confining clay layer, and a deeper aquifer extending beneath the surrounding area.

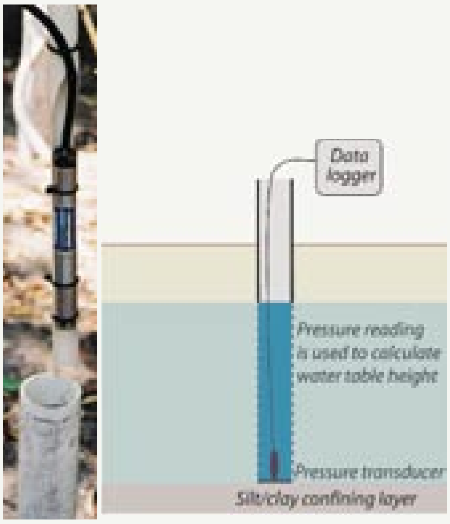

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Figure 3. A typical well in the perched aquifer, with a pressure transducer installed to measure fluctuations in water table depth.

More wells were then sunk within and outside the riparian zone, over an area of 500 square metres, to try to map the groundwater flow paths and the boundaries of the shallower water table. From these wells, and measurements of surface water (stream) flow after rain, the team confirmed the presence of the shallow, perched water table in the riparian zone floodplain, which was filled laterally by subsurface flow from the stream. This perched water table was transient and gradually drained once stream flow stopped. Under these conditions, the potential for a waterlogged and anaerobic environment in the carbon-rich root zone of the floodplain was high.

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A new conceptual model for denitrification in the riparian zone around the small, ephemeral stream was then proposed (Figure 4). The model demonstrates that after rain, surface runoff from the catchment flows down the stream. While much of the flow continues down the stream channel, some of it ‘leaks’ laterally into sub–surface soils to form the perched water table within the riparian floodplain. Provided conditions are right, nitrate is then removed by denitrification before the water drains back to the stream some distance further along. While only a small proportion of the total stream flow may be diverted this way at any one point, the process could be quite significant if it occurs repeatedly as the water flows downstream.

The next question to be addressed was the speed of groundwater flow, or ‘hydraulic residence time’. This is a key factor in determining the extent of contact between nitrate and biologically active

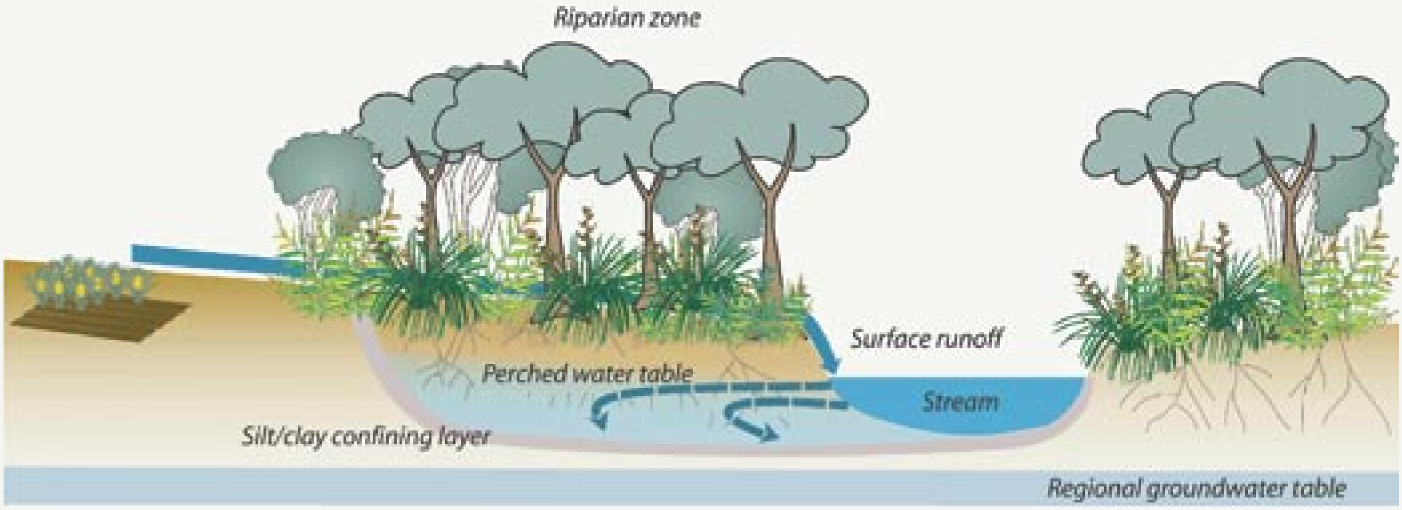

Figure 4. New conceptual model for the ephemeral stream system showing conditions when stream flow occurs following surface runoff. A proportion of the stream flow moves laterally to form a perched water table within the carbon–rich root zone of riparian vegetation. If conditions are suitable, denitrification can remove nitrate from this shallow groundwater before it drains back to the stream.

soil or sediment surfaces, and therefore the opportunity for denitrification to occur.

One way to measure hydraulic residence time is to follow the movement of a ‘tracer’, such as a bromide solution, through the soil, from an ‘injection’ well to a nearby ‘capture’ well (Figure 5). At a time when the stream is flowing, a small amount of the solution is added to the injection well, and its rate of flow measured by monitoring the time it takes to appear in the capture well. Using this ‘natural gradient’ tracer method, and computer modelling, a flow rate of 5–7 cm/day was determined...slow enough to give denitrifying bacteria a chance to remove nitrate from the water, before it drains back to the stream.

Denitrification potential

With the presence of the three key denitrification drivers confirmed, the team’s next step was to test the denitrification potential of soils and aquifer sediments at the site. To do this they conducted laboratory experiments using soil or sediment taken at different depths in the floodplain of the ephemeral stream.

Soils were incubated in bottles under anaerobic conditions, with varying amounts of nitrate and a carbon source (acetate) added. Denitrification rates were then measured periodically over the next fourteen days.

Under these controlled conditions, denitrification peaked after 2–3 days in the bottles containing surface soil (from the 0–30 cm layer) and added acetate, and resulted in a very high removal rate of up to 15 milligrams of nitrate-nitrogen per kilogram of dry soil per day. When no acetate was added, the peak denitrification rate in this soil was lower but still substantial (around 6 mg nitrate–N/kg dry soil/day) since the denitrifying bacteria were reliant for their energy needs on the much lower levels of organic carbon available from the soil.

Denitrification rates in soil from lower in the profile (30–100 cm) were generally lower than those in surface soil. Without added acetate, the peak rate was around 3 mg nitrate–N/kg dry soil/day, roughly half the rate found for the surface layer of soil under similar conditions.

Figure 6 shows typical examples based on these results, of the changes in denitrification rates with time and with soil depth.

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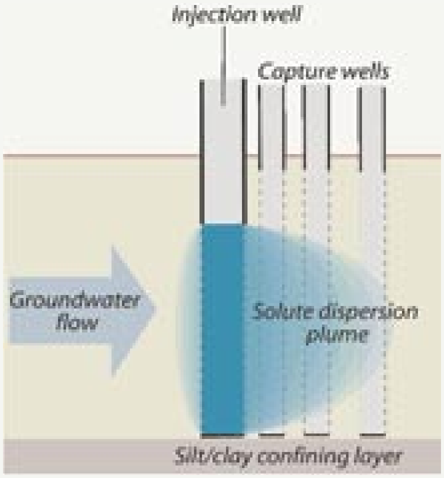

Figure 5. Injection and capture well network used in tracer studies to measure the rate and direction of groundwater flow, and nitrate removal.

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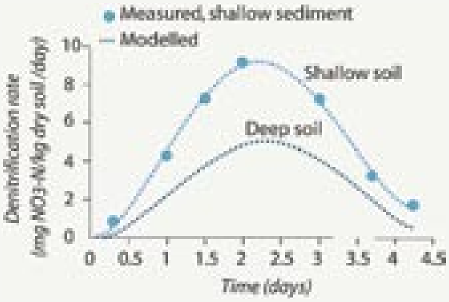


Figure 6. Typical examples of results from the laboratory incubations, showing the differences in denitrification rates with time and with depth in the soil profile. The dotted lines show examples of the modelled relationships that were derived using laboratory data; the blue circles show measured data.

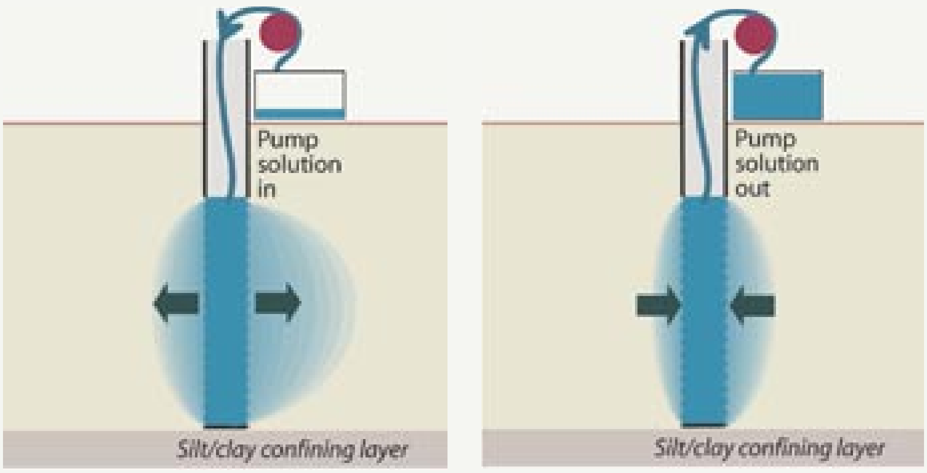
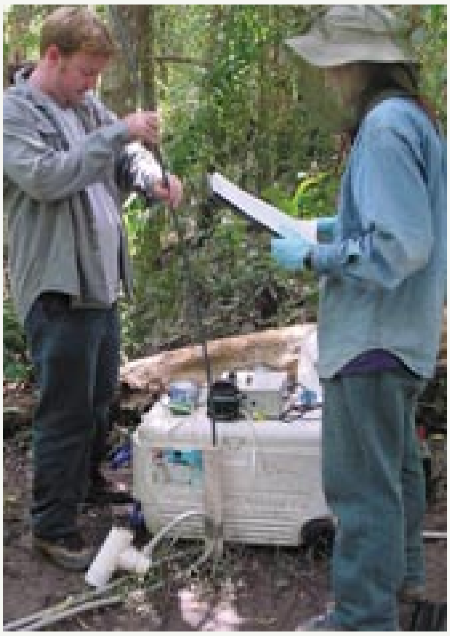


Figure 7. The push–pull technique, where solutes (nitrate, acetate and a tracer) are pushed a short distance from a well into the perched water table and then pumped out again some hours later. The ratio of nitrate and tracer in the recovered solution is then compared with that in the solution pumped into the well, to estimate the amount of nitrate removed.



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Field denitrification

To compare these laboratory results with what happens in the field, the team again turned to tracer studies. Two techniques were used; the first using the injection–capture well approach (as used to measure groundwater flow), and the second using a 'push–pull' technique.

To perform the push–pull technique, a solution containing a known concentration of nitrate, a carbon source (acetate), and a bromide tracer, was 'pushed' or forced a short distance from a well into the surrounding perched water table (Figure 7). After several hours, the solution was then pumped back out of the well, and the ratio of nitrate and bromide in the recovered solution measured. The injection–capture well method similarly involved measuring the ratio of nitrate and bromide in the solution recovered from the capture well, following application of measured amounts to the injection well.

Using both of these approaches, the team was able to show that in each case relatively less nitrate was recovered than bromide.

As some of the nitrate in these solutions may be taken up by plant roots or assimilated by soil microorganisms, the exact contribution denitrification makes to nitrate removal can't be calculated.

The most important question is, however: can riparian zones remove significant amounts of nitrate from groundwater before it enters our waterways? The results of this study show that they can. For example, in one injection–capture well experiment, the team found that 40% of the nitrate added, was removed over a six–day period (Figure 8).

Bucket model

With these successes under their belt, and a string of laboratory and field data, the team set about developing a new model that would estimate the denitrification potential of the site, which could then be applied to other sites with similar hydrology.

The new 'bucket model' is so named because the riparian zone floodplain of the ephemeral stream acts like a bucket. When water enters the floodplain from the stream, it is assumed to remain stationary, just like a bucket full of water. But as soon as the stream level drops or stream flow ceases, the

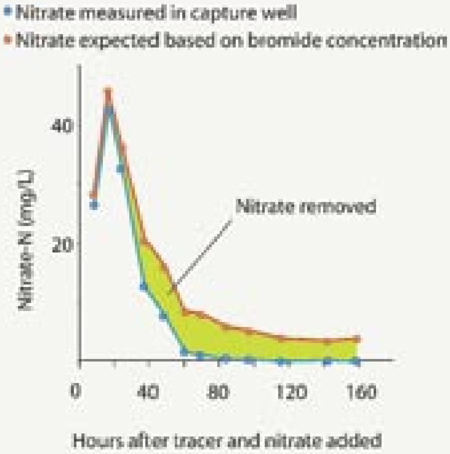

Figure 8. An example of results from a natural gradient tracer study. The expected nitrate concentrations were based on results for bromide. Differences between the measured and expected results indicate the loss of nitrate that occurred between the injection and capture wells over a period of 6–7 days.

water drains away laterally as if through a hole in the side of the bucket. With this concept in mind, the model divides a one square metre area of the floodplain into eight buckets, stacked on top of each other (Figure 9). The top four buckets contain the most carbon, being closer to the surface, and therefore have the highest denitrification potential. The buckets lower down, however, are the first to fill with water, achieve anaerobic conditions and initiate denitrification. To cope with these differences, each bucket is represented by a different mathematical algorithm or formula, which calculates the denitrification rate. As soon as a bucket is filled with water, the appropriate algorithm is activated, and a new nitrate concentration is calculated every 10 minutes.

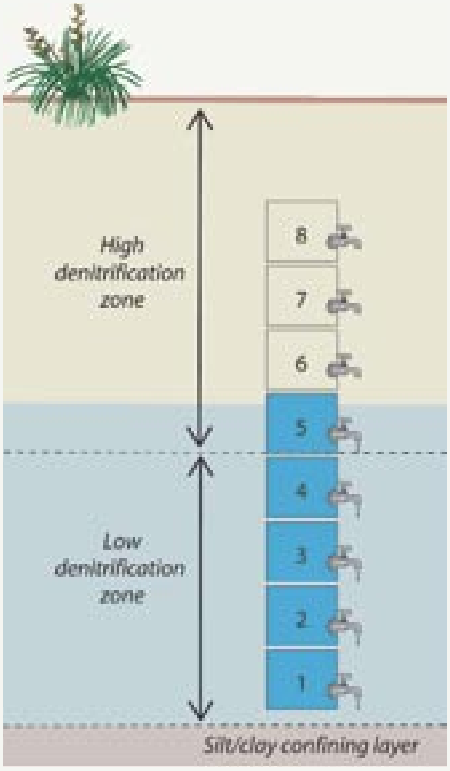

Figure 9. A new conceptual 'bucket' model for denitrification potential in the perched aquifer system.

Ongoing studies

The team plans to use their conceptual and bucket models at a catchment scale. To do this they first need to develop a computer–based mapping technique to identify stream reaches where shallow groundwater inflows are likely to occur. This will help target priority areas where riparian management activities can be most effective in reducing nitrogen inputs to streams and, when coupled with the models, will allow the impacts of various management options to be evaluated. These techniques will be incorporated into a larger 'catchment modelling toolkit' being developed by the CRC for Catchment Hydrology (see *www.catchment.crc.org.au*).

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The ephemeral stream studies are now being extended to Coochin Creek itself, to gain insights into groundwater – surface water interactions and riparian zone processes in the larger perennial stream system. Methods developed at the ephemeral stream site,

Guidelines for management

This research is providing new insights into the importance of riparian zone management for protecting water quality in Australian catchments. Present management guidelines provide advice for minimising the inflow to streams of sediment, nutrients and other contaminants from surface runoff. This study focuses on another potential pathway for nitrogen to enter streams – via sub–surface (groundwater) flow paths.

Already, the research has shown the potential for denitrification to be an important 'service' that riparian zones can perform. In a practical sense, this means that a management priority for these areas is to increase their denitrification potential by building–up levels of organic carbon in the soil.

Riparian vegetation plays a key part in adding carbon to soil reserves. Perennial plant species (or combinations of species) that are deep–rooted and have an abundance of roots are likely to provide ideal conditions. In addition, soil carbon reserves can be protected by minimising disturbance, thus practices such as the removal of vegetation and cultivation are best avoided.

Not all riparian zones transmit groundwater to streams so it is important to be able to identify those areas where this is most likely to occur. This should be made possible through ongoing research, with the development of a catchment–scale mapping technique, to be used in combination with the knowledge of local community members.

should allow key denitrification processes to be assessed at Coochin Creek and other sites. In a new project – In–stream and riparian zone nitrogen dynamics – being conducted in collaboration with the University of Western Australia and Monash University, the methods will be tested and refined in contrasting geographic areas. Links between riparian zone nitrogen cycling processes and in–stream nutrient cycling will also be examined in this project, which is funded by Land and Water Australia and the Murray–Darling Basin Commission.

The team's research is also feeding into the comprehensive scientific program that is underpinning implementation of the South–east Queensland Regional Water Quality Management Strategy, and wetlands studies being conducted by the CRC for Coastal Zone, Estuary and Waterway Management.

In conclusion

The study has shown that Australian riparian systems can play a role in reducing nitrogen loads entering streams, and thereby help protect downstream water quality and ecosystem health. Ongoing research will provide further information and modelling tools for evaluating management options and optimising the potential for nitrate removal in targeted riparian lands across the country.

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