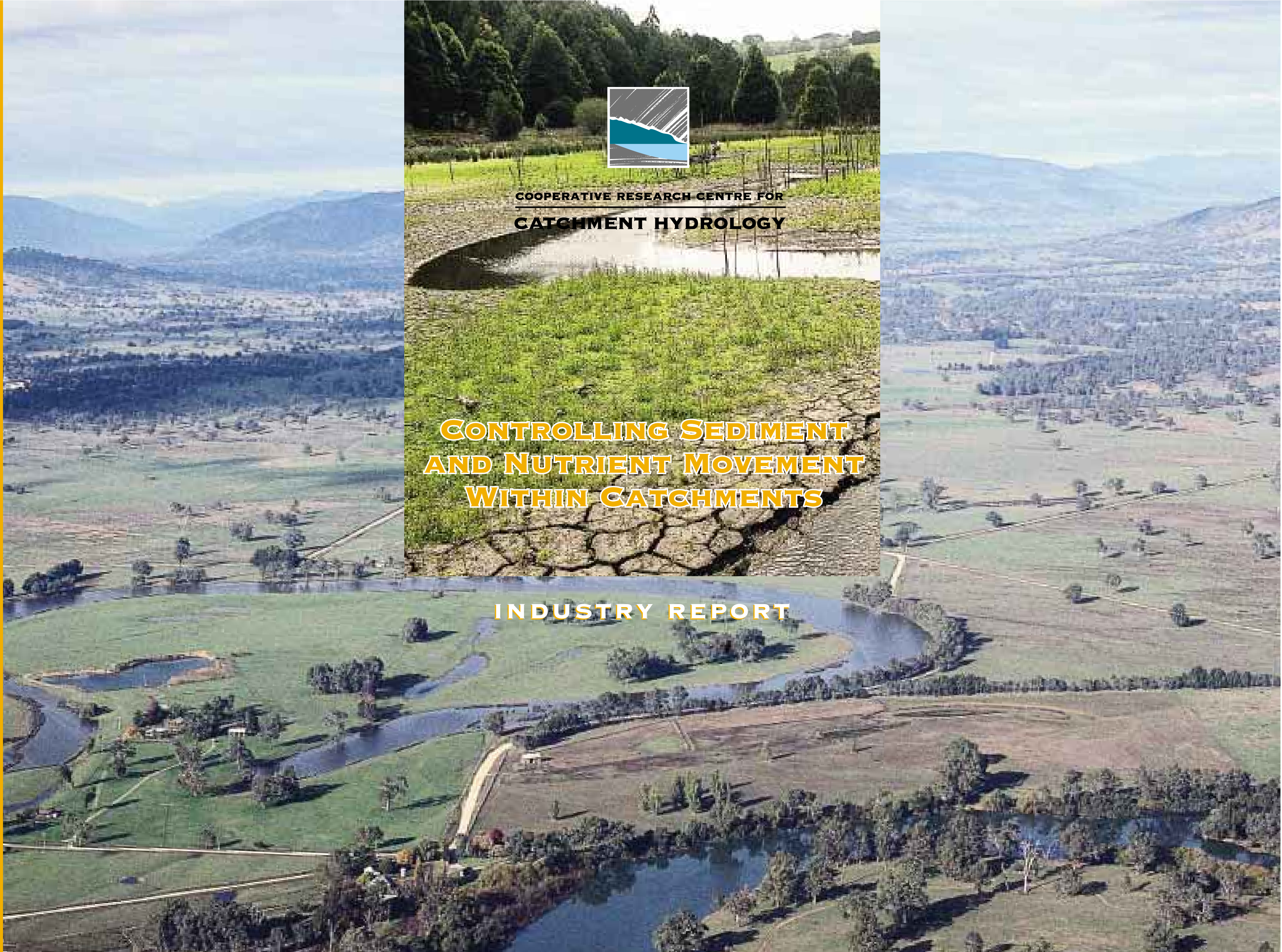
COOPERATIVE RESEARCH CENTRE FOR

CATCHMENT HYDROLOGY



Controlling Sediment and Nutrient Movement Within Catchments

INDUSTRY REPORT

Controlling Sediment and Nutrient Movement Within Catchments

by

Peter Hairsine

COOPERATIVE RESEARCH CENTRE FOR
CATCHMENT HYDROLOGY

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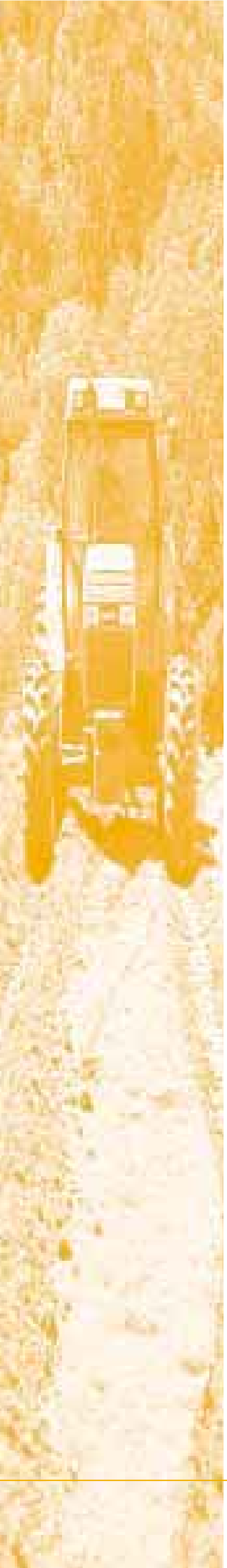

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Controlling sediment and nutrient movement within catchments

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F o r e w o r d

This Industry Report is one of a series prepared by the CRC for Catchment Hydrology to help provide agencies and consultants in the Australian land and water-use industry with improved ways of managing catchments.

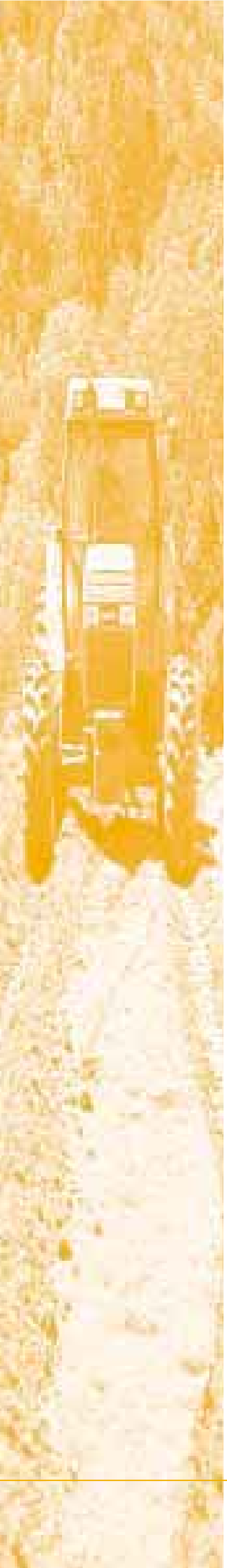
Through this series of reports and other forms of technology transfer, industry is now able to benefit from the Centre's high-quality, comprehensive research on salinity, forest hydrology, waterway management, urban hydrology and flood hydrology.

This particular Report presents key findings from the project in the CRC's waterway management program entitled, 'Controlling delivery of sediment and nutrients to water supply catchments'. (More detailed explanations and research findings from the project can be found in a separate series of Research Reports and Working Documents published by the Centre.)

The CRC welcomes feedback on the work reported here, and is keen to discuss opportunities for further collaboration with industry to expedite the process of getting research outcomes into practice.

Russell Mein

Director, CRC for Catchment Hydrology



Preface

The project described in this report was part of the CRC's Waterway Management Program. From 1993-96, the program had two core projects:

- Controlling the delivery of sediments and nutrient in water supply catchments (Project B1)
- Factors controlling river channels and gully stability (Project B2)

  Project B1 - the subject of this report - focused on the movement of sediment- and nutrient-laden rainfall runoff before it enters a permanent stream. Project B2 focused on sediment movement in the stream and on stream stability. Some aspects of the research related to the whole catchment, while others were linked solely to riparian zone management.

  All program researchers worked closely with the water industry and community groups. Project B1 involved collaboration between CSIRO, the University of Melbourne, Royal Melbourne Institute of Technology (RMIT), Melbourne Water, Monash University, and a local community group, the Tarago Catchment Steering Committee.

The following people made significant contributions to this project:

- Leon Bren, the University of Melbourne: *land resource and buffer zones*
- Jim Brophy, CSIRO Land and Water
- Neville Carrigy, formerly CSIRO Land and Water
- Fiona Dyer (PhD student) CSIRO Land and Water and University of Melbourne: *sediment tracing*
- Peter Hairsine (Project Leader), CSIRO Land and Water: *buffer zone performance, fires, and runoff*
- Nira Jayasuriya, RMIT: *water quality analysis*
- David Mackenzie, CSIRO Land and Water: *buffer zone performance*
- John Riddiford, Melbourne Water: *agency liaison*
- Susie Richmond, CSIRO Land and Water
- Craig Smith, formerly CSIRO Land and Water
- Vasantha Siriwardhena (PhD student), RMIT and Melbourne Water: *water quality analysis*
- Christoph Zierholz (MSc student), Australian National University and CSIRO Land and Water: *fires and runoff.*

Further support was provided by:

Fred Booker (University of California); the late Jack Caller (Melbourne Water); Gary Caitcheon (CSIRO); Peter Fogarty (NSW Department of Land and Water Conservation [DLWC]); Bruce Gardiner (Vic. Department of Natural Resources and Environment [DNRE]); Paul Gribben (Monash University); Richard Habgood (DNRE); Junhua Huang (CSIRO); Dr Dasarath Jayasuriya (Melbourne Water); Steven Lacey (State Forests of NSW); Simon Mockler (CSIRO); Chris Moran (CSIRO); Scott Morrison; Andrew Murray (CSIRO); Jon Olley (CSIRO); Nigel O'Shea; David Pearce (NSW National Parks and Wildlife Service [NPWS]); Peter Wallbrink (CSIRO); Ian Watson (Melbourne Water); Ken and Mary White; Gary Winter (Melbourne Water); Damian Woods; Robert Yurisich (Melbourne Water); and Hannes Zierholz.

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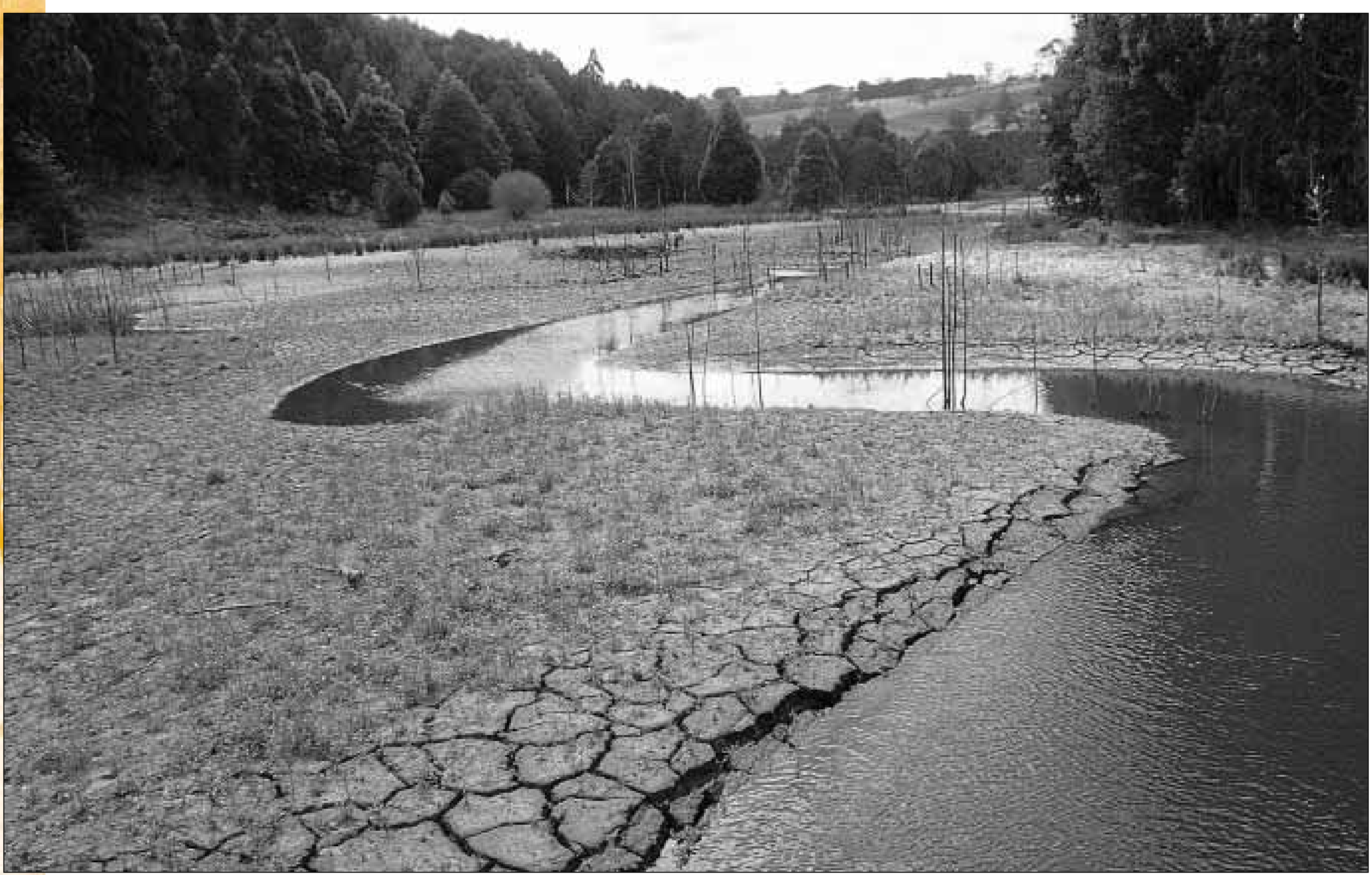


The backwater of the Tarago Reservoir, West Gippsland, Victoria

INTRODUCTION: CATCHMENT MANAGEMENT AND WATER QUALITY

As Australia moves into the second half of the Decade of Land Care, the state of our streams continues to be a cause for concern. In many instances, water quality is deteriorating and stream instability increasing, at great cost to downstream users. Stream managers are harnessing scant resources and community goodwill through Rivercare, Land Care and Streamwatch, and other programs in an attempt to reverse current trends. The task is immense and the solutions require a long-term commitment by all interest groups.

The role of new knowledge in stream rehabilitation is crucial. Research outcomes need to be well targeted and suited to local conditions. The recent trend to 'soft-engineering' methods means the time between research and implementation is necessarily short. This demands close cooperation between the water industry, community groups, and researchers.

Safe and cost-effective water supplies — from catchments and reservoirs — are important not only to rural communities, but to people living in towns and cities. Many water supply catchments include a variety of land uses, such as grazing and horticulture, which can introduce potential pollutants, in the form of sediment and nutrients, to drinking water supplies.

RESEARCH APPROACH AND FIELD SITE SELECTION

The CRC Project B1: 'Controlling the delivery of sediments and nutrients in water supply catchments', set out to improve our understanding of water-borne sediment and nutrient movement across a water-supply catchment.

Various control approaches, including vegetation, were investigated for their effectiveness in reducing pollutant movement. Investigations combined stream water quality monitoring, on-slope investigations with rainfall simulators, sediment tracer techniques, and computer-based modelling. Together, these techniques provide a near-complete picture of where pollutants originate, and the rate at which they move through the catchment. While some project outcomes are specific to the study catchment, other outcomes are generic.

Field work focused on the Tarago Reservoir catchment in west Gippsland, Victoria. This catchment is part of the water supply system for Melbourne. In recent years, the reservoir has had significant water quality problems, including an algal bloom in April 1991. It appears likely that these water quality problems are associated with past land management practices in the catchment.

Melbourne Water and related agencies have been taking a community-based approach to implementing catchment management strategies in the Tarago Reservoir catchment, as well as commissioning these scientific investigations.

To summarise, the objectives of the CRC's research project were to:

- assess the major sources of sediment and associated pollutants to the Tarago Reservoir
- assess the performance of grass buffer strips and near-natural riparian vegetation in controlling the supply of sediment to the reservoir
- assess the resource impacts of using buffer zones as a water quality control measure
- assess the changes in runoff and erosion associated with a major bush-fire.

Buffer zone performance under rainfall simulator, Tarago

TWO APPROACHES TO CATCHMENT WATER QUALITY

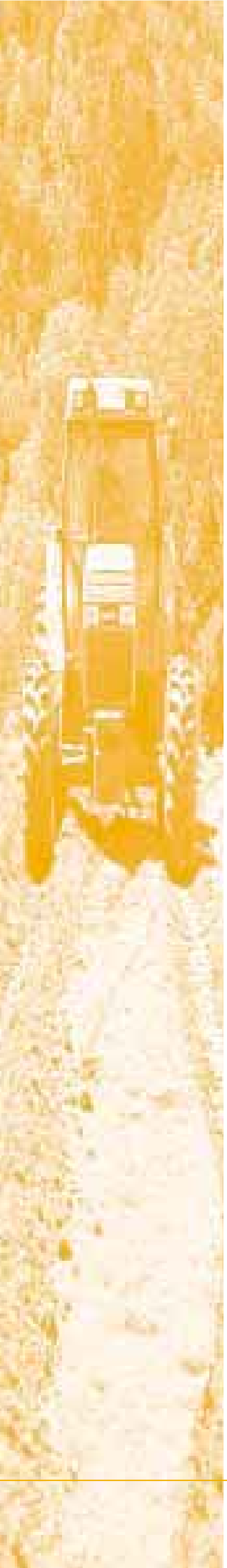
- Sediment tracing. By comparing the signature of sediment in the reservoir with the signatures of potential sources, the reservoir sediment's source - and that of associated nutrients being delivered to the reservoir - can be identified.

- **Water quality monitoring**. Through monitoring water quality at a series of outlets of sub-catchments, the contribution of these catchments to the river flow can be determined.

Both techniques provide catchment managers with information about which areas of the catchment to target to improve water quality. Table 1 lists the advantages and disadvantages of both approaches, and may be used to assist investigators in finding an appropriate single, or combined, approach.

Approach	Advantages	Disadvantages
Sediment tracing	• Measures the sediment as accumulated through all types of flow conditions. • Measures of sediment contribution are retrospective. • There is a clear statistical test between a source, with a unique signature, and the measured sediment. • Trends in sediment loads or changes in source can be determined by depth in a deposit and by dating.	• Is normally unable to give a measurement of the frequency of the sediment concentrations at a sample location. • Measurements are available at a few specialist laboratories only. • Potential sources are limited to those areas having a unique signature.
Water quality monitoring	• Gives a measurement of the frequency of water quality conditions at a point. • Trends in water quality are simply examined (but may be difficult to prove statistically). • Analytical measurements are widely available through many laboratories.	• Sampling at high flows, when much of the sediment and associated pollutant load is often limited. • Requires extensive monitoring to generate enough useful data. • Requires monitoring enough stations to be representative of the whole catchment. • Relating measurements at a point to particular land use and other sources of sediment is not possible.

Table 1: Relative advantages and disadvantages of sediment tracing and water quality monitoring approaches to in-stream pollutant investigations.



1. TRACING SEDIMENTS TO SOURCES

In 1991, the Tarago Reservoir experienced a minor, toxic blue-green algal bloom that caused heightened community concern about nutrient supply to the reservoir.

Phosphorus (P) is regarded as the limiting nutrient for algal growth in inland waters. Much of the phosphorus transported in Australian streams is associated with soil and organic particles, because it has a strong affinity for such particles. This phosphorus subsequently becomes available for algal growth. Thus, to slow down the delivery of sediment and associated phosphorus to Tarago Reservoir, catchment-based works should be targeted at sediment sources.

The CRC carried out a series of sediment-tracing experiments in the Tarago catchment to identify the major sources (land use and soil type) of sediment and phosphorus to the Tarago Reservoir.

The tracing technique

What is sediment tracing? The distinctive properties of possible sediment-source soils are compared to the same properties observed in reservoir sediments. This enables researchers to determine the proportion of sediment coming from different source soils (Figure 1).

The advantage of this approach is that the total amount of sediment deposited in the reservoir is sampled. This takes into account all types of flow conditions and associated sediment loads entering the reservoir over its life.

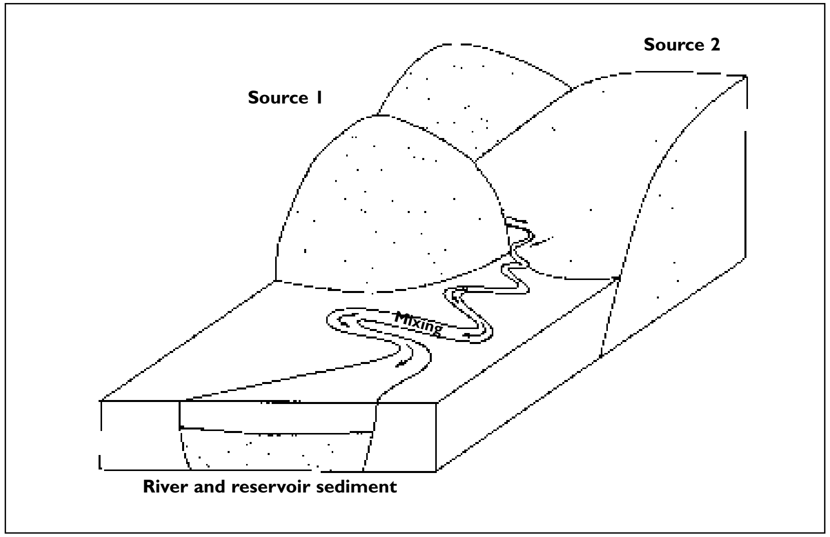


Figure 1: The sediment tracing process. Two source materials (1&2) — identifiable by their distinctive characteristics — are delivered to the stream, mixed, and deposited as reservoir sediment. The proportions of source 1 and 2 characteristics in the sediment tell us that the sediment is derived mainly from source 1. This process becomes more complex for three or more possible sources.

In the Tarago catchment, CRC researchers identified three source areas:

- The Tarago and LaTrobe State Forests, largely drained by the Tarago River. The area is forested, subject to logging operations, with an underlying granite geology.
- The agricultural land along the north-east and far south-west side of the catchment. The geology of these areas is mainly basalt, although some granite and sedimentary rock occurs along the edge of the Tarago River, east branch.
- The hills — which are farmed — that drain directly into the lower half of the reservoir. These lie above mainly sedimentary rocks, with some basalt on the ridges.

The composition of soils in these source areas is a function of the geology underneath them. Thus, Tarago catchment soils can be classified by an area's dominant geology: granite-based; basalt-based; or sedimentary/basalt-based.

The next step for the researchers was to find a measurable property or feature that is different in each of the potential source soils. This is known as 'characterising' the potential source, and the measured property for each source is known as a 'fingerprint'. The feature used to characterise potential sources must remain unchanged during transportation and over time.

The properties that can be used to characterise potential source areas are:

- relationships between major elements (Al_2O_3 /SiO_2 and Al_2O_3/Fe_2O_3)
- mineral magnetic properties
- radionuclide composition.

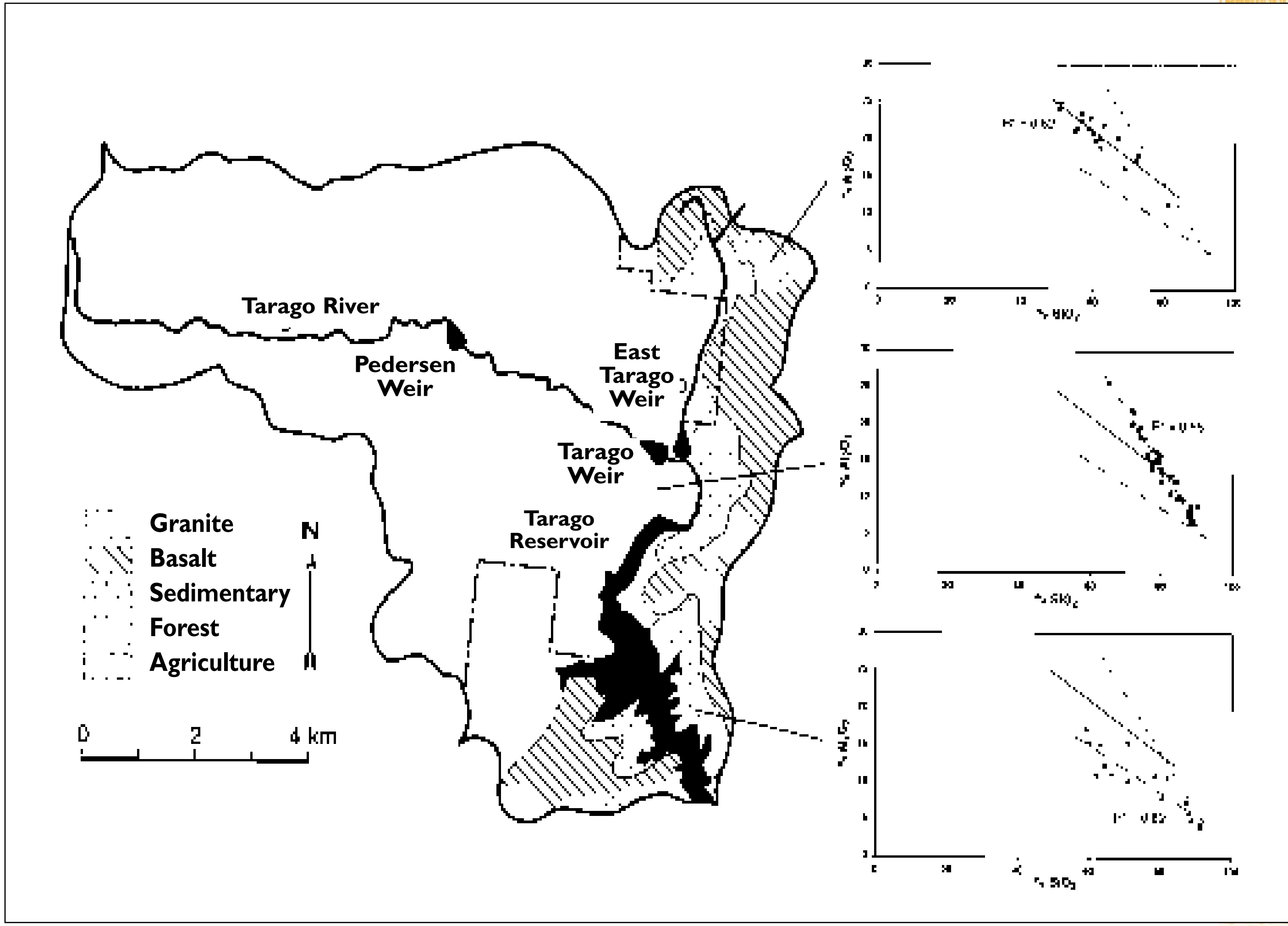
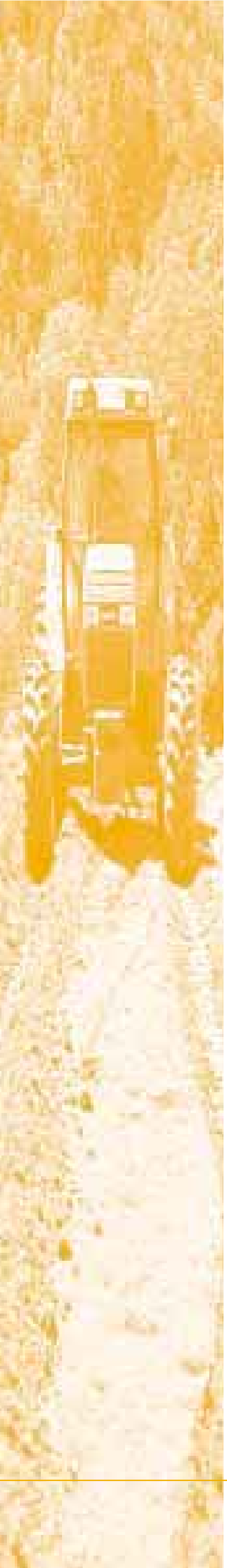


Figure 2: Each soil from a different potential source area has a distinct Al_2O_3/SiO_2 relationship, making this a useful fingerprint in sediment sourcing.

The Al_2O_3 and SiO_2 data from the soils of the different source areas in the Tarago catchment are displayed in Figure 2. Each of the soil types has a distinct Al_2O_3/SiO_2 relationship. These relationships are a function of the soil minerals, which in turn are a function of the underlying geology.

The spread of data along the lines is due to differences in particle size distribution — with finer particles containing less SiO_2 than coarser particles.



Comparing potential source soils with sediments

The final step in the CRC research was to characterise the sediment, comparing results with the fingerprints of potential sources.

Bottom sediment samples were collected from a number of locations in the reservoir and from the weirs on the east and west branches of the Tarago River. Comparisons of the Al_2O_3/SiO_2 profiles in these sediment samples with those found in the soils (Figure 3) showed that:

- Sediment from the East Tarago Weir (ETW1 and ETW2 in Figure 3) has Al_2O_3/SiO_2 relationships that are consistent with a mixture of soils from all three geology types. This is expected given the geologies around the East Tarago River.
- Sediment from the weirs on the Tarago River — upstream of the confluence with the east branch (TW1, TW2, and PW) — have Al_2O_3/SiO_2 relationships consistent with the finer, granite-based soils. This is expected, as the Tarago River at this point drains only granite-derived soils.
- Sediment flowing into the reservoir from the Tarago River (R3) is a mixture of contributions from the granite soils (supporting forestry) and the basalt-derived soils (supporting mainly horticulture and dairying). This is again consistent with the dominant geologies upstream of this point.
- There is very little contribution of the granite soils to the sediment in the deep water of the reservoir (R1–R4). This sediment comes from basalt-derived soil and/or sedimentary/basalt-derived soil.

To test the findings of the sediment tracing studies, depth and particle size data were obtained from post-impoundment sediment in a series of cores taken from a number of locations around Tarago Reservoir. The location and depth of the sediment is shown in Figure 4.

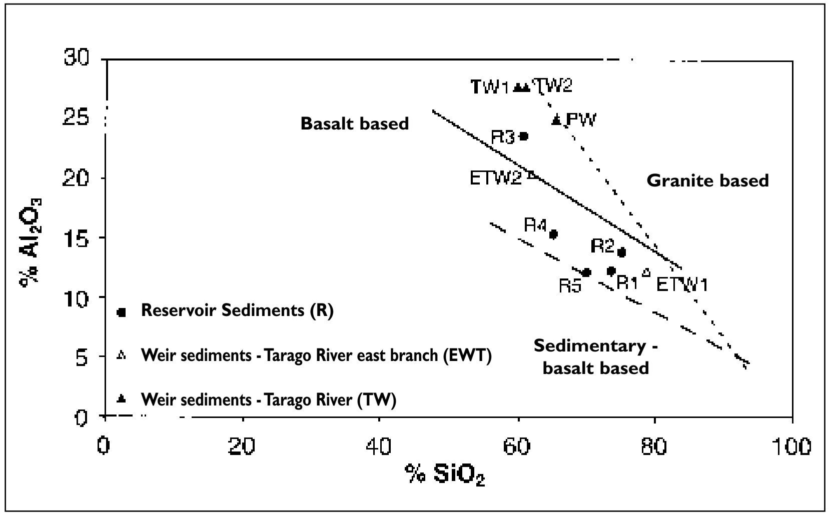


Figure 3: Comparison of Al_2O_3/SiO_2 in the sediment of the East Tarago River and Tarago River weirs and in sediment from the Tarago Reservoir, with the Al_2O_3/SiO_2 relationships observed in the soils of the three potential sources.

If the Tarago River was the dominant contributor of sediment to the reservoir, the sediment distribution pattern should be deepest and coarsest at the inlet of the Tarago River, with the particle size grading to very fine towards the dam wall.

The particle-size data, however, show coarser material in the inlets of the reservoir, with a greater proportion of fine material towards the centre and deeper water of the reservoir. There is some fining of the sediment from the top end of the reservoir towards the dam wall. However, this may be due to transportation of finer material from all sources towards the dam wall. What is observed, therefore, is more consistent with an even contribution of sediment from the immediate slopes — with the deeper amounts of post-impoundment sediment found on the edges and in all the inlets of the reservoir.

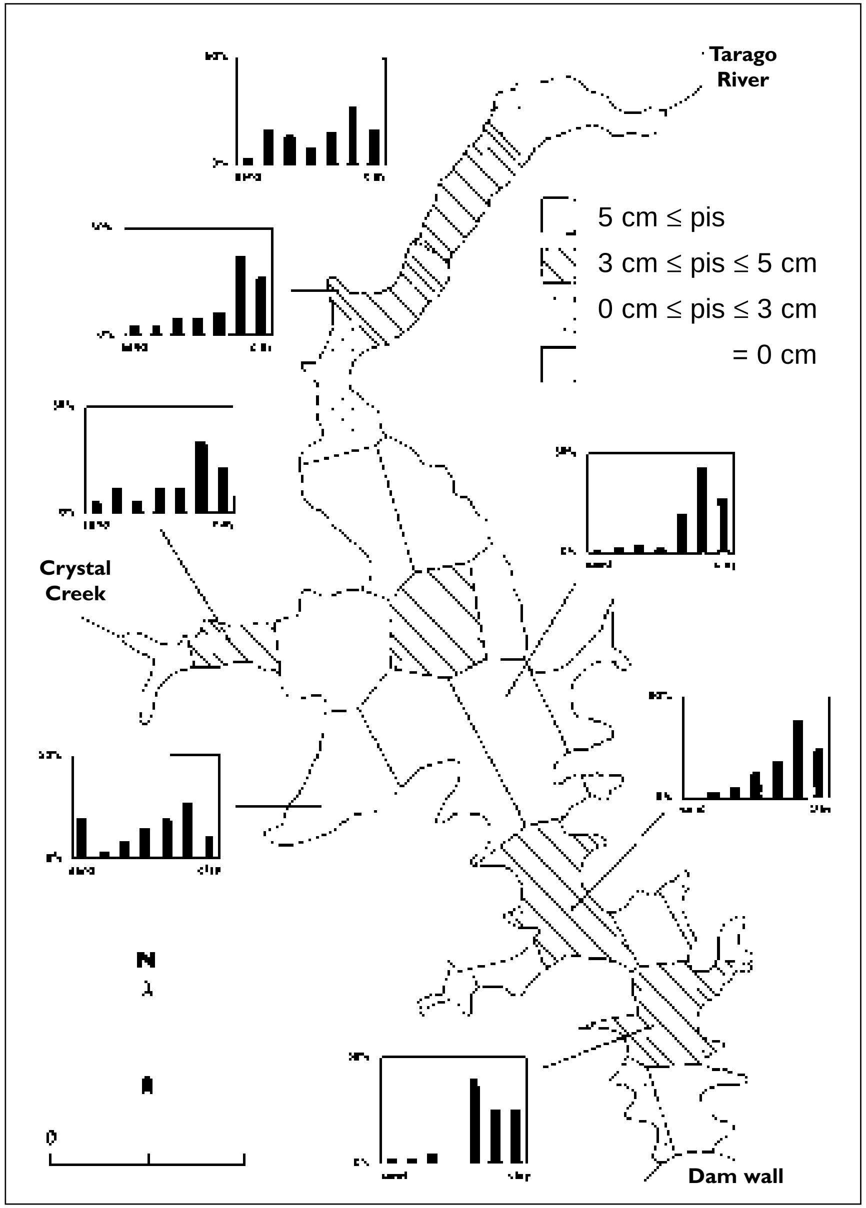


Figure 4: Depth distribution of post-impoundment sediment (pis) in cores taken from the bottom of Tarago Reservoir. The size distribution of the post impoundment sediment is given for selected locations.

Key findings from catchment tracing studies

- The correlations between the major elements SiO_2 and Al_2O_3 are useful tracers for identifying potential sediment sources that are different in parent material (geology).
- Both the distribution of sediment and the tracing studies indicate that the immediate slopes around the reservoir (sedimentary and basalt soils supporting agricultural activities) are the dominant contributors of sediment to the deeper water of the Tarago Reservoir.
- Although the Tarago River drains most of the catchment, the river appears to deliver sediment mainly to the upper end of the reservoir, with little sediment travelling to the deeper sections of the reservoir. Tracing studies in the Tarago catchment will determine the relative contributions of surface, subsurface (gullies or stream walls), and shoreline erosion to reservoir sediment. Other experiments are looking at the effects during transport of abrasion on the properties used in sourcing.

2. Measuring pollutant sources using water quality data

The conventional method of assessing the contribution of different land uses to a waterway's sediment and pollutant load is to measure concentrations in contributing streams, and relate these values to the land use in each sub-catchment. The Tarago catchment is well suited to this type of analysis because it has:

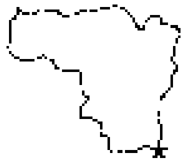
- land-uses that closely correspond with the sub-catchments
- land-uses that closely correspond with soil types
- near-continuous sediment and other pollutant records for the major tributaries draining the catchment above the Tarago Reservoir.

The CRC analysed water quality data from the east and west Tarago Rivers, as well as the Tarago Reservoir, in order to:

- assess tributary and reservoir health using water quality indicators
- assess trends in the water quality data associated with different land uses
- cluster water quality measurements, so that expensive measurements can be rationalised in future monitoring
- assist in the construction of a deterministic model of the catchment.

Researchers collected water quality data and flow records for the east branch of the Tarago River, the west branch of the Tarago River, and the reservoir. The sample locations are shown in the first column of Table 2. The analysis involved factor, discriminant, and trend analysis.

Junction of the east and west branches of the Tarago River.

Sampling location	Water quality constituent	Maximum permissible level: Often exceeds	Maximum permissible level: Seldom exceeds	Maximum permissible level: Never exceeds	Highest desirable level *: Often exceeds	Highest desirable level *: Seldom exceeds	Highest desirable level *: Never exceeds
Tarago Reservoir 	Colour	✓			✓		
	pH			✓	✓		
	Turbidity		✓			✓	
	Iron	✓					
	Mn		✓				
	NO_3-N			✓			
Tarago River 	Colour	✓			✓		
	pH			✓	✓		
	Turbidity		✓		✓		
	[illegible]	✓					
	Mn		✓				
	NO_3-N			✓			
East Tarago River 	Colour	✓			✓		
	pH		✓		✓		
	Turbidity	✓			✓		
	Fe	✓					
	Mn	✓					
	NO_3-N			✓			

* There are no prescribed desirable levels for iron, manganese and nitrate

Table 2: Summary of the frequency at which water sampled at the stations in the Tarago River catchment exceeds the drinking water standards of the NHMRC/AWRC (1987).

Key findings of water quality study

- Table 2 summarises six key water-quality measures for the three main sampling locations in the catchment of the Tarago Reservoir. The results are presented as frequency of exceeding desirable and permissible levels as set down by the National Health and Medical Research Council/Australian Water Resources Council (1987) and World Health Organisation guidelines (1984). This gives a picture of river condition for the purposes of determining frequency of water treatment needs, and exposure to pollutants of the stream ecology.
- The east Tarago River — which predominantly drains agricultural land — has more frequent, elevated levels of turbidity and manganese.
- The factor analysis suggests that water colour, turbidity, and total phosphorus are largely associated with surface runoff processes.
- The same analysis suggests that a significant proportion of iron and manganese are derived from groundwater sources.
- The monthly average concentrations of total phosphorus, nitrate and turbidity are significantly higher for the east branch of the Tarago River than those of the west branch (Figure 5).
- None of the water quality measures show seasonality, except nitrate in the east branch of the Tarago River.
- Given the clustering of water quality measures in the analysis, future measurements could be rationalised to fewer locations.
- The study highlights the importance of controlling erosion as a catchment protection measure. Surface transport of pollutants was shown to be the most important factor in pollutant movement within the catchment. The sediment-attached component is significant for certain pollutants such as phosphorus.

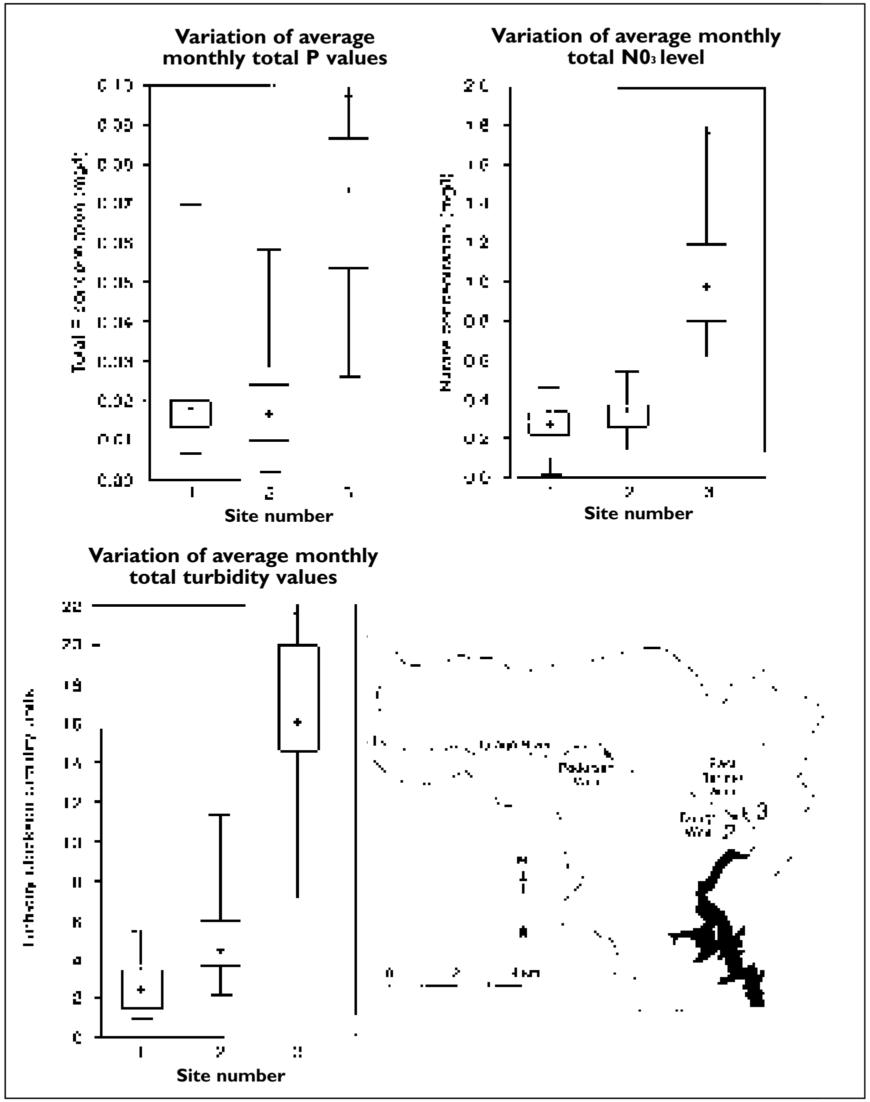
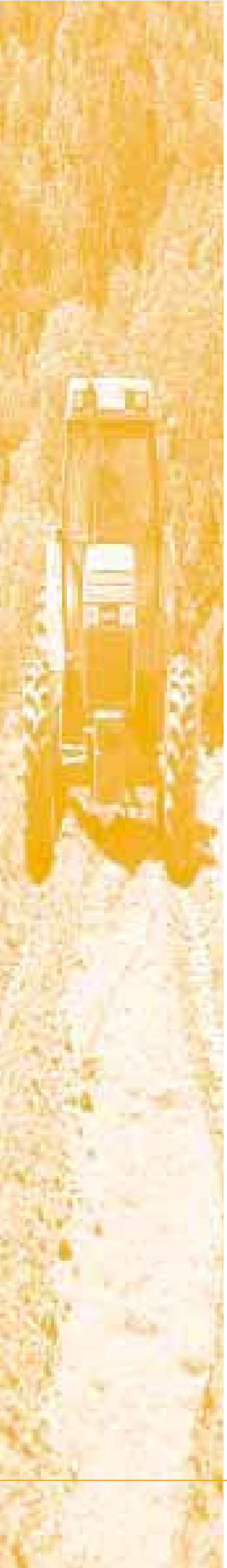


Figure 5: Monthly values of total phosphorus (P), nitrate (NO_3), and turbidity at three sampling locations in the Tarago Reservoir catchment.



CONTROLLING OUT-OF-STREAM SEDIMENT MOVEMENT

For some catchments, much of the stream sediment comes from hillslope surfaces, rather than gullies. Soil conservation measures have two goals — to reduce the loss of productive soil on-site, and to minimise the impact of soil and associated pollutants off-site, further down the catchment. Controlling off-site sediment movement along hillslopes was the focus of this study.

Sediment movement along hillslopes can be largely controlled through soil conservation measures such as conservation tillage. These measures, however, may be constrained by farm production objectives. In such cases, landholders can apply other measures to reduce the movement of sediment to streams, yet maintain farm productivity.

This part of the CRC project focused on the use of grass filter (or buffer) strips and near-natural riparian vegetation to trap sediment and associated pollutants before they enter streams. The study objectives were to:

- understand the relative importance of factors — such as buffer strip width, hillslope shape, and sediment characteristics — that affect the sediment-trapping performance of buffer zones
- compare the sediment-trapping performance of grass filter strips and near-natural riparian vegetation
- assess the ability of both buffer types in trapping soil-attached pollutants (specifically phosphorus) travelling with the sediment.

Maximising the trapping effectiveness of grass filter strips

Grass buffer strips are areas of grass placed between hillslopes and streams (or small drainage lines) to reduce the input of sediment and soil-attached pollutants to waterways from upslope agricultural areas. Combined with tree plantations, grass filter strips are increasingly used in agroforestry systems.

The effectiveness of grass filter strips in trapping sediment and nutrients can vary. The most effective of the filter strips tested by the CRC trapped more than 90 percent of the incoming sediment, and more than 70 percent of the incoming nitrogen (N) and phosphorus (P). Other studies, however, have found filter strips to be far less effective in trapping sediment and sediment-attached nutrients.

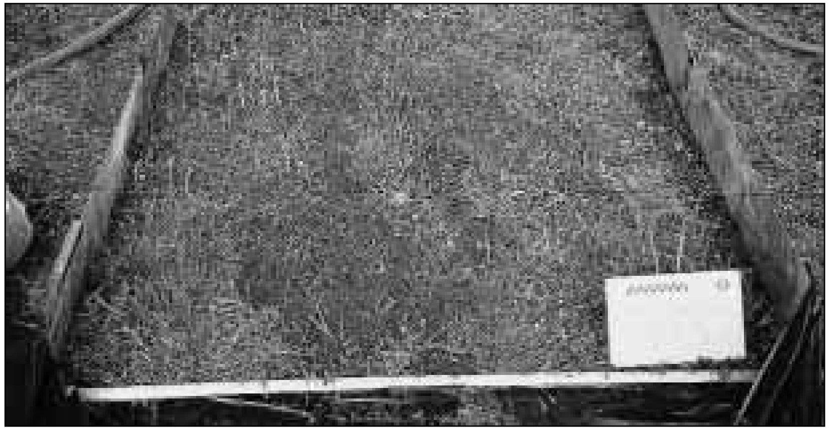
To identify the factors that influence the performance of grass buffer strips, the CRC carried out a series of field experiments in the Tarago catchment in which it evaluated buffer strip configuration, vegetation type, and inflow rates of sediment and nutrients. The detailed measurements of sediment sizes entering and leaving the filter strips enabled researchers to produce more reliable conclusions than previous studies.

CRC researchers monitored the trapping effectiveness of grass filter strips immediately downslope of a freshly tilled potato field with furrows running downslope. Filter strip performance was compared for a range of flow conditions.

Tillage for potatoes on a farm adjacent to the East Tarago River.

Water was applied to a 20-metre length of two furrows to produce overland flow rates at the filter strip of about 0.07, 0.14, and 0.28 litres per metre width, per second. These rates were applied sequentially to each of the hillslopes, generating a range of sediment and nutrient inputs to the grass filter strips. Filter strips were three metres or six metres wide, and enclosed on two sides. A rainfall simulator was positioned over the strips to simulate resuspension of deposited material during storms. The experiments were conducted at two locations, each with different soils (a krasnozem and a granite-derived loam) having differing aggregation and distribution of nutrients across the sediment size classes.

Sediment and nutrient samples — from grass filter strip inlets and outlets — were taken at regular intervals during each 20-minute episode of overland flow. A subset of these samples was analysed for sediment size.



Sediment fans formed in grass filter strips in the Tarago catchment experiments.

KEY FINDINGS OF GRASS FILTER STRIP RESEARCH

Sediment trapping in grass filter strips is controlled by two factors:

- the range of flow velocities in the grass
- the cumulative mass of sediment deposited in the sediment fan compared with the capacity of the buffer to store sediment (Figure 6).

Figure 6 compares the performance of the three-metre wide filter strip to the six-metre wide filter strip for the krasnozem soil. Coarse sediment becomes trapped in the first two metres of the filter strip as a fan structure, due to the reduced velocity of overland flow in the grass. With a near-uniform cover of grass, coarse sediment would only re-emerge if the fan extended across the entire filter strip width.

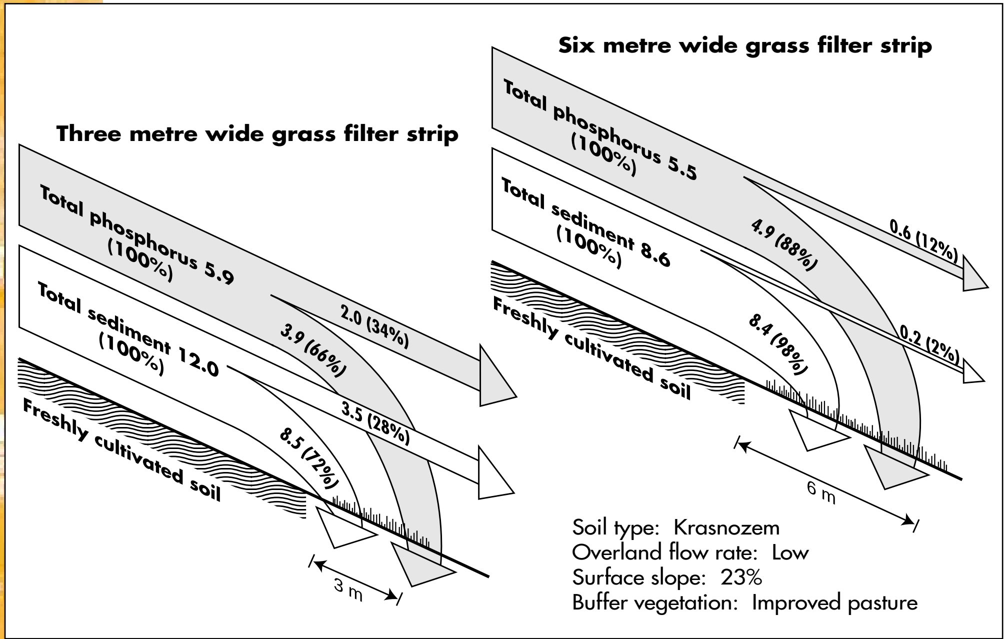


Figure 6: Buffer zone performance of three-metre wide and six-metre wide filter strips under low flow conditions applied to the krasnozem soil.

For most soils, phosphorus and other particulate pollutants are found on the clay and organic surfaces of finer soil particles. Soil aggregation will affect the occurrence of these particles in sediment size distribution. For the krasnozem soil, the sediment entering the filter strips was well aggregated, so that a large portion of the phosphorus was attached to clay and organic surfaces contained within the aggregates. This resulted in the highly effective trapping of phosphorus in these filter strips.

Grass filter strips are less effective in trapping phosphorus for weakly aggregated soils, compared with well aggregated soils. Figure 7 compares the performance of the six-metre grass filter strip for two diferent soils.

The krasnozem soil had higher input sediment and total phosphorus fluxes because of a much higher nutrient concentration in the original soil and the higher sediment concentration leaving the potato field.

Figure 8 compares the performance of the six-metre grass filter strip for the granite-derived loam across a range of flow rates. With increasing water flow rate per unit width, the ability of the filter strip to trap sediment remains high.

However, increases in the amount of very fine sediment passing through the filter results in reduced trapping ability for total phosphorus with increasing water flow.

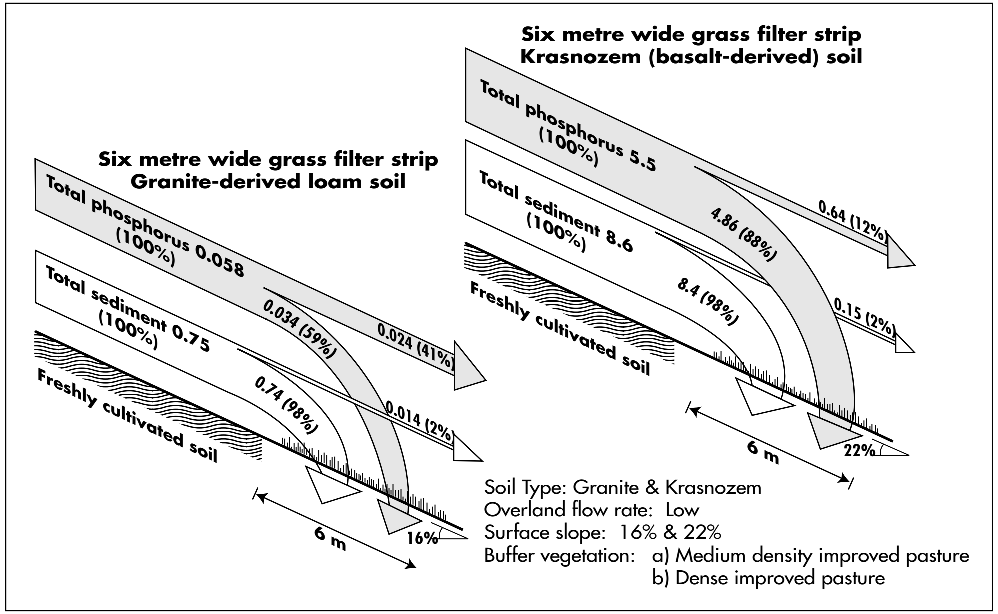


Figure 7: Buffer zone performance of a six-metre wide filter strip under low flow conditions applied to two soils: weakly-aggregated, granite-derived loam (low phosphorus concentration), and well-aggregated krasnozem soil (high phosphorus concentration).

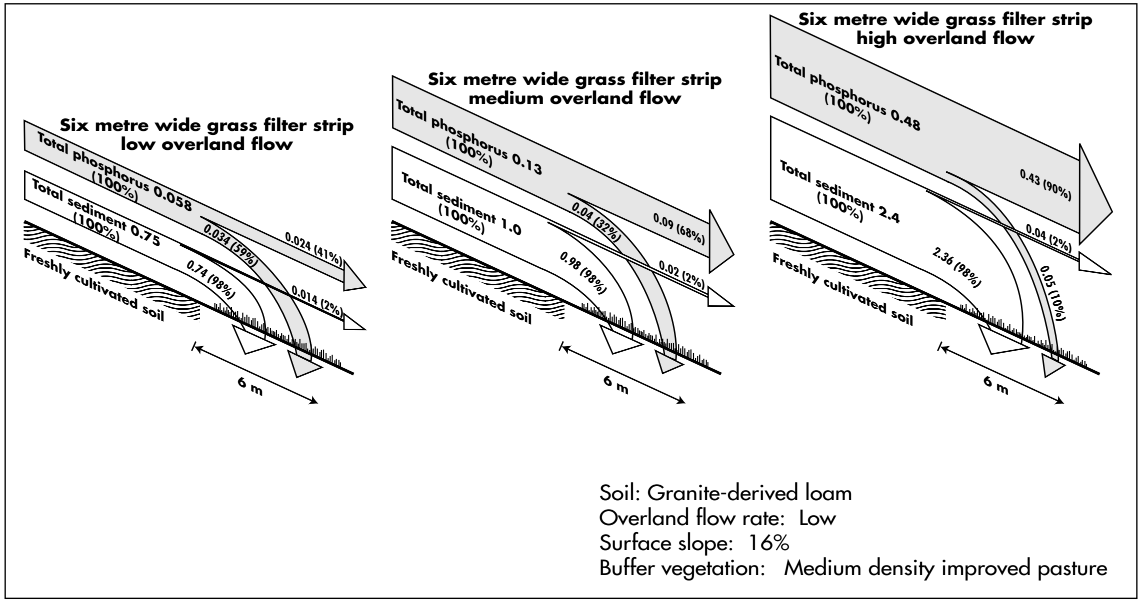


Figure 8: Buffer zone performance of a six-metre wide filter strip for the range of flow conditions applied to the weakly-aggregated, granite-derived loam of low phosphorus concentration.

From this and other studies, CRC researchers concluded that the important factors influencing the performance of grass filter strips (Table 3) include:

- rate of upslope soil erosion
- vegetation density and structure in the buffer zone
- water flow rate through the filter strip
- fineness of the sediment

Table 3: Maximising the trapping of sediment and related nutrients in buffer zones.

Factors influencing buffer performance in sediment and nutrient trapping	Management strategies to maximise buffer performance
Rate of soil erosion upslope	• Conservation practices on the hillslopes, such as minimum tillage
Vegetation density and structure in the buffer zone	• Use a vegetation in the buffers which has dense, near uniform ground cover
The water flow rate passing through the filter strip as influenced by its position on the hillslope and degree of convergence	• Minimise runoff from the contributing hillslope through conservation practices • Make buffer zones wider where flows converge, such as in hollows
The fineness of the sediment as influenced by soil type and structural degradation	• Conservation practices on hill slopes to maintain stable soil aggregates • Use wider buffers below areas producing fine sediment
The land slope	• Position buffers in lower slope areas adjacent to channels • Buffers can still be highly effective on land slopes up to 25 per cent.

How do grass filter strips and riparian forests differ in sediment-trapping ability?

Riparian forests are zones of native and/or introduced trees alongside streams which influence chemical, ecological and physical processes (Table 4). Many revegetation projects in Australia are targeting riparian zones to plant native vegetation, with aims differing between community groups and water supply agencies, the latter being most often concerned with stream water quality.

In deciding whether to use grass filter strips or natural riparian vegetation, practitioners should consider their relative value and functional importance (Table 4), and how well each system fulfils its functions. In this study, the effectiveness of grass filter strips and near-natural riparian zones in trapping sediment and nutrients was compared for a range of environmental conditions.

A near-natural riparian zone with simulated overland flow.

Table 4: The functions of near-natural riparian forests and grass buffer strips.

	Near-natural riparian forests	Grass filter strips
Chemical and physical functions	• Shading of stream, impacting stream water temperature, algal growth, fish • Filtering sediment and nutrients from upslope • Stream bank stability • Storage and extraction of nutrients in solution • Wind breaks • Control of spray drift to streams	• Filtering sediment and nutrients from upslope • Storage and extraction of nutrients in solution (limited) • Stream bank stability (limited) • Control of spray drift to streams (limited)
Ecological functions	• Source of nutrients and energy for in-stream ecology • Source of large woody debris, a component of in-stream habitat • Protection of in-stream habitat for a range of plants and animals, including fish • Habitat for wildlife, including pest controlling predators	• Reserve of native grasses

As in the first experiment, artificial overland flow carrying sediment and nutrients was generated on a ploughed field at different rates. The soil was the granite-derived loam. The overland flow then entered the buffer zone.

Four types of buffer zones were investigated:

- a three-metre wide grass strip
- a six-metre wide grass filter strip
- a six-metre wide riparian forest
- a combined buffer of a three-metre wide grass filter strip and a three-metre wide riparian forest.

The vegetation in the buffer zones is described in Table 5.

Table 5: Description of the vegetation in the buffer zones investigated.

Layout of buffer	Vegetation
3 m wide grass buffer strip (GFS)	Dense near-uniform pasture dominated by *Dactylis glomerata* (cocksfoot) and *Agrostis capillaris* (brown top bent grass)
6 m wide grass buffer strip (GFS)	Dense near-uniform pasture
3 m wide grass buffer strip (GFS) + 3 m wide riparian forest (RF)	Medium density grass some patchiness, and complete cover of litter, including leaf mat, sparse woody debris, and understorey shrubs dominantly *Kunzea ericoides*, *Olearia stellulata* (daisy bush), and *Cassinia longifolia* (common cassinia)
6 m wide riparian forest (RZ)	Complete cover of litter, including leaf mat, sparse woody debris, and understorey shrubs

In a second experiment, the spatial variability of overland flow was measured for overland flow without sediment, passing through grass filter strips and near-natural riparian forests. The discharge and flow velocity of overland flow was measured for a range of total inflows at 0.1 metre segments across a three-metre wide hillslope strip.

Figure 9 compares the performances of the six-metre wide grass filter strip and the six-metre wide riparian forest. In both cases, sediment leaving the buffer zone is mainly in the fine sediment size classes. For the low rate of overland flow, the performance of both sediment and total phosphorus trapping was similar. With increasing rates of overland flow, the performance of the riparian forest followed the trend for the grass filter strip (Figure 8), and the riparian forest showed slightly lower trapping efficiencies for phosphorus.

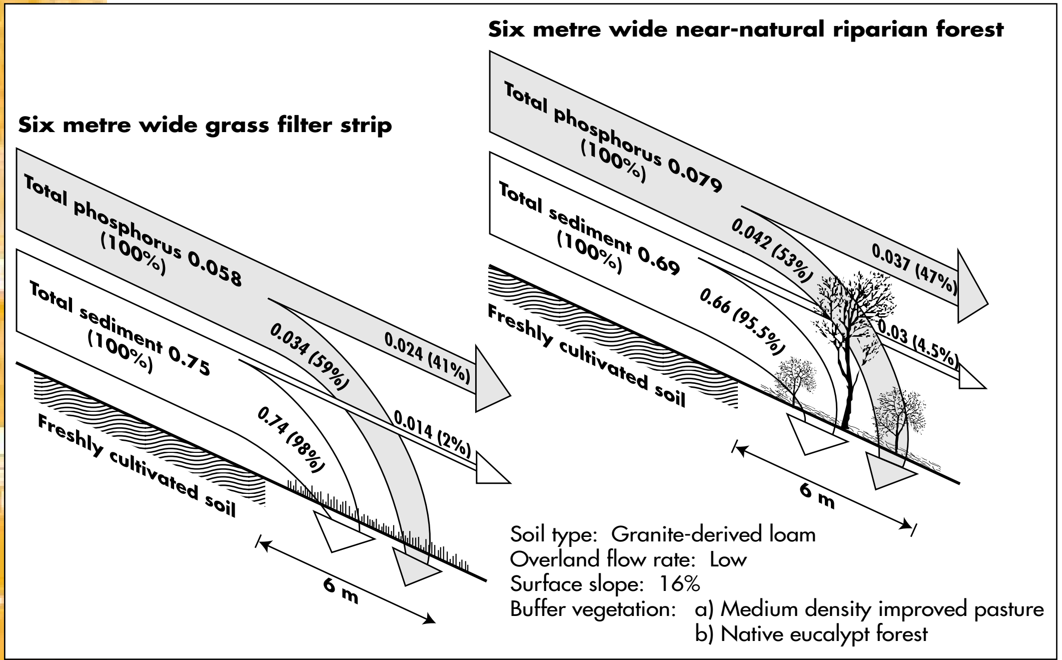


Figure 9: Buffer zone performance of a six-metre wide grass filter strip and a six-metre wide riparian forest.

Figure 10 compares the performances of the six-metre wide filter strip and the combined system of grass and riparian forest. The combined system performed similarly to the grass filter strip, with high sediment trapping ability and moderate phosphorus trapping ability. The grass in the combined system was not as dense as the grass filter strip due to shading and soil moisture in the adjacent forest.

The general picture that emerged from these experiments is that near-natural riparian zones are similar to grass filter strips in their ability to trap sediment and attached pollutants. The reduced trapping effectiveness at higher rates of overland flow appears to have been associated with a slightly increased velocity of overland flow in the riparian forest (Figure 11).
The grass filter strip had lower, more uniform, flow velocities than those of the riparian forest.

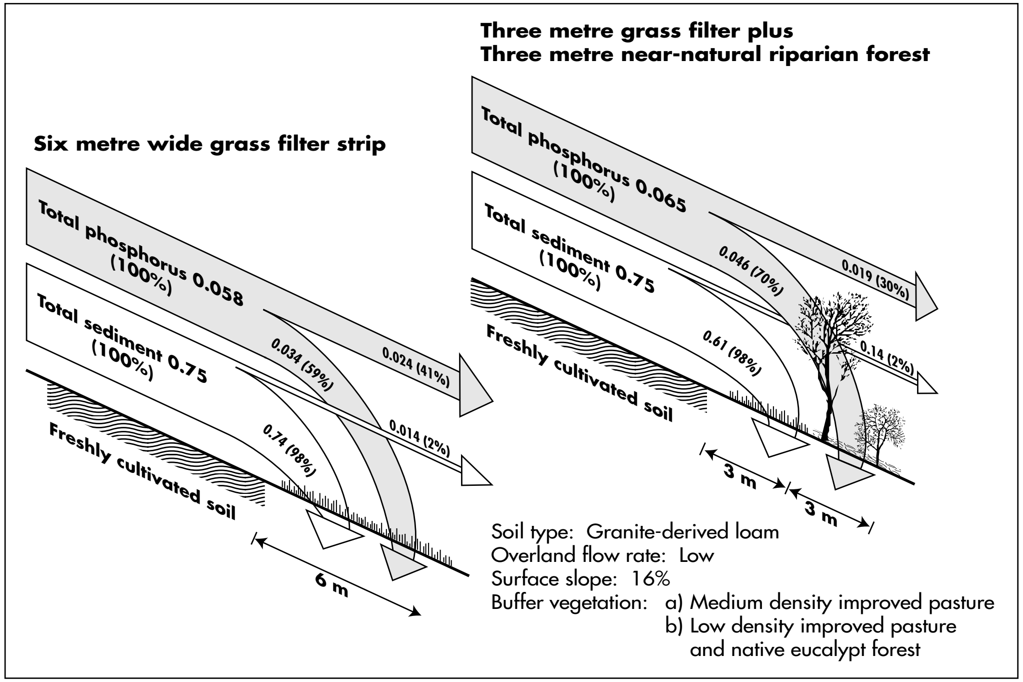


Figure 10: Buffer zone performance of a six-metre wide filter strip and a combined system of grass filter and riparian forest.

These research outcomes have since contributed to the development of riparian zone guidelines, which address physical and ecological problems of riparian zones. They contain a menu of riparian zone management approaches, so that the user may combine methods to achieve the desired functions listed in Table 4.

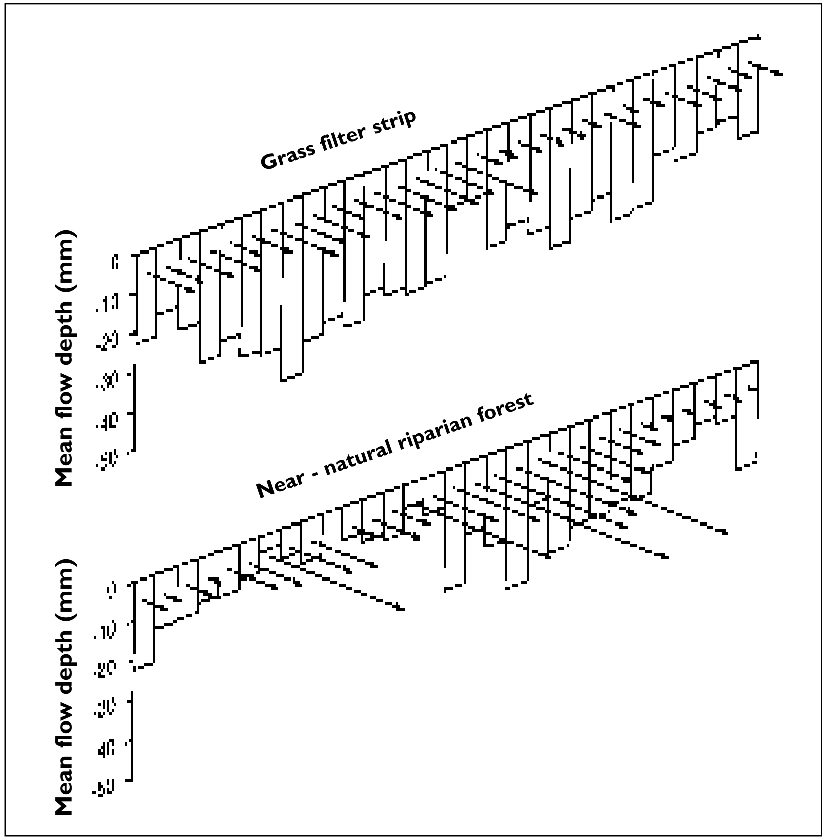


Figure 11: Spatial variability of overland flow depths shown by bars, and velocity shown by arrows, for a grass filter strip and a near-natural riparian forest.

EFFECT OF RESERVING RIPARIAN BUFFER ZONES ON LAND AND FOREST RESOURCES

Reserving riparian buffer zones to control erosion and water quality could reduce the amount of available productive land. In agricultural environments, riparian buffer zones may reduce cultivation or grazing areas, but introduce other benefits. In forestry environments, any forest timber resource disproportionately represented in the riparian buffer zone of a catchment area may result in a disproportionate reduction in available timber resource.

The CRC investigated these management issues within the Tarago Reservoir catchment. Specific objectives were to:

- assess the relationship between buffer strip width and the fraction of catchment area reserved for this purpose
- examine the operational difficulties associated with access to 'islands' of timber resource, resulting from buffers of a range of widths
- assess the fraction of timber resource associated with the reserving of a range of buffer zone widths.

Using GIS modelling, researchers combined terrain data for the Tarago catchment with high resolution colour air photography to define the stream network, and used existing mapping to define the extent of timber resources.

KEY OUTCOMES OF BUFFER ZONE/LAND RESOURCE RESEARCH

- Figure 12 shows the approach taken in defining the area occupied by buffers of different widths for a complex stream network. Figure 13 shows the percentage of catchment area occupied by buffer zones (‘y’) of varying widths (‘w’) for the forested portion of the Tarago Reservoir catchment. This can be summarised by the relationship:

$$y = -0.489 + 0.650w - 0.001w^2$$

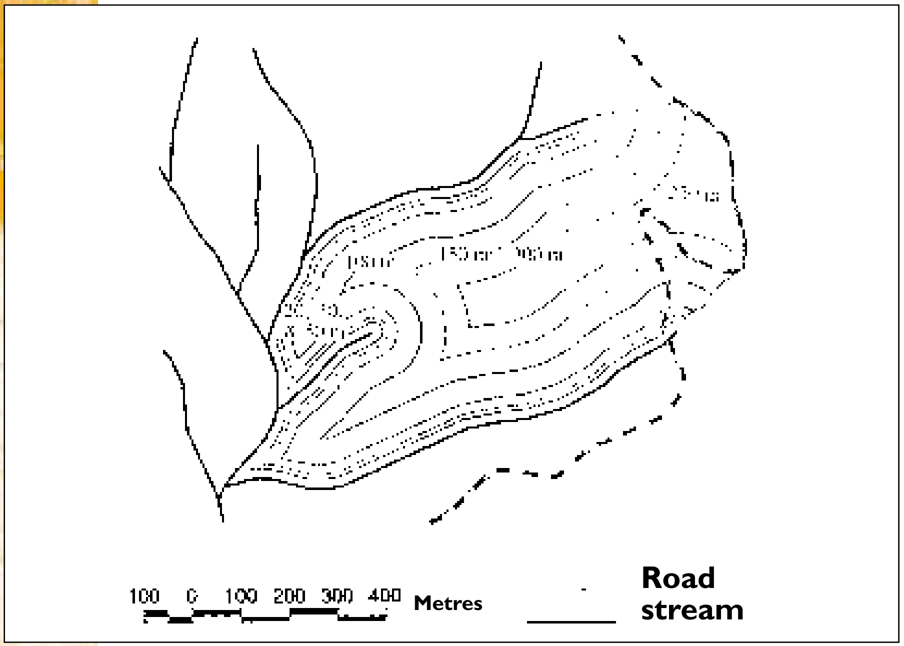


Figure 12: Approach for defining the area occupied by buffers of varying widths for a complex stream network.

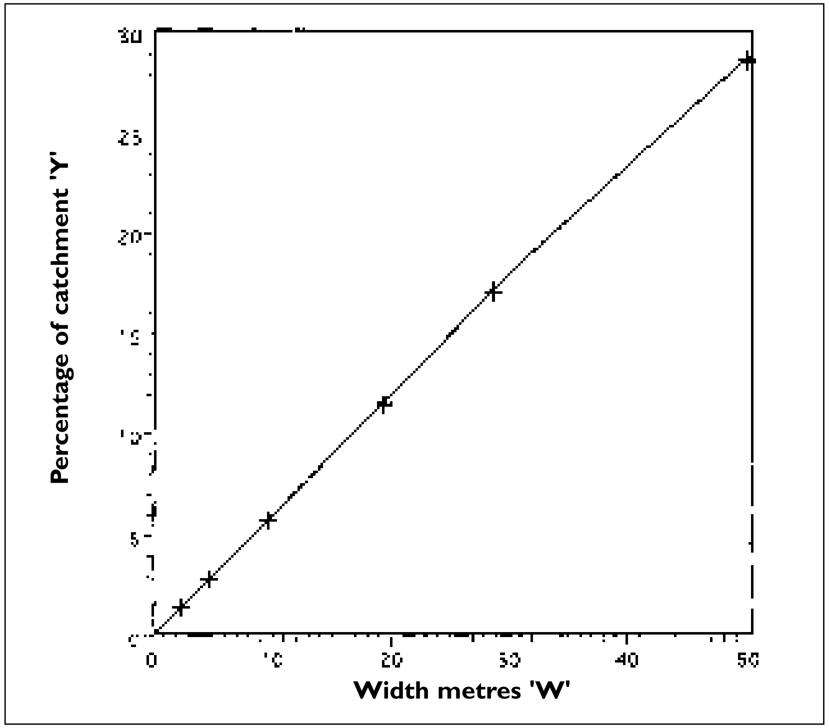


Figure 13: Percentage of the catchment area occupied by buffer zones, of varying widths, in the forested portion of the Tarago Reservoir catchment.

- Access to timber resources may be limited by the existence of buffer zones where vehicle access is limited. For buffer widths equal to or less than 30 metres, the number of ‘islands’ is low. For buffer zones of greater width, areas of timber resources become complex in shape and difficult to assess with a rapid increase in the number of islands.
- For the Tarago and LaTrobe State Forests, the timber value per unit area of land adjacent to the stream was only slightly greater than the average value of the timber resource per unit area.

RUNOFF AND SEDIMENT MOVEMENT FOLLOWING FIRES

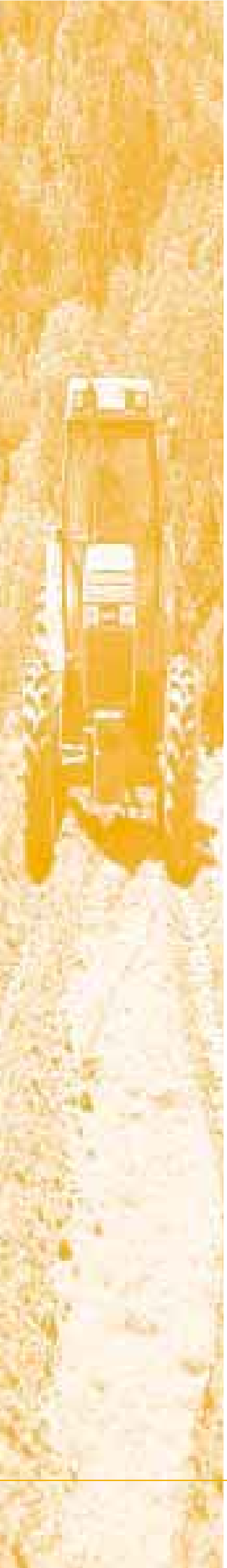
In January 1994, major fires affected much of eastern NSW. Members of the CRC project team were approached by the NSW Department of Land and Water Conservation to study the impact of the fires on runoff and erosion rates in the affected areas — in particular, to investigate the relationship between fires, soil properties, and runoff and erosion processes.

Royal National Park was one of the areas most severely affected by the1994 fires, which burned 97 percent of the park. In the few weeks following the fires, some rainstorms occurred, resulting in extensive runoff and surface soil erosion. The CRC focused its efforts on the heathlands and sandy soils in the eastern portion of the park, which is a particularly vulnerable environment and has a high conservation value due to its biodiversity. The soils proved to be hydrophobic (or water repellent), which means that much of the rain became runoff.

The research included field measurements of hydrophobicity and rainfall simulations in fire-affected areas. Experiments carried out shortly after the fire were repeated after two years to assess the ecosystem recovery. Other studies had indicated the risk of runoff and erosion to be greatest immediately after the fires, declining in subsequent months as vegetation reappeared. Some studies had suggested that soil properties would also change after the fire, with the soil becoming less hydrophobic.

KEY FINDINGS OF POST-FIRE EROSION AND RUNOFF RESEARCH

- Post-fire, the study site's ground surface was resistant to soil erosion. Although extensive runoff was observed after the fire, the rainfall simulator results showed that only rare, large storms could produce relatively small amounts of erosion. This finding supports the 'do nothing' approach to post-fire sediment control in burned, but otherwise undisturbed, areas. The extensive erosion that did occur in some areas was associated with tracks and fire trails. These structures intercepted and concentrated overland flow on less-resistant surfaces associated with human disturbance. Remediation should be confined to tracks and trails where flow should be slowed and dispersed.
- Soil properties, not vegetation cover, probably controlled runoff generation after the fire. No significant change in runoff rates occurred between four months and 28 months after the fire. In this period, however, vegetation cover recovered significantly, so high rates of runoff probably existed for both unburned and burned surfaces (despite no unburned area being available for comparison of runoff rates).
- The hydrophobic behaviour of the soil — the controlling factor on the generation of runoff — did not change between four months and 28 month after the fire. This is consistent with the above finding. As with the runoff results, either the recovery process was slow or the high levels of hydrophobicity existed in the unburned and burned soils.



SUMMARY OF PROJECT OUTCOMES

Through its research for Project B1: 'Controlling delivery of sediment and nutrients to water supply catchments', the CRC has:

- developed a method — based on the chemistry of major elements present in different rock sources — to spatially trace sediment sources within a catchment
- interpreted sub-catchment contributions of pollutants to a reservoir — and associated temporal trends — based on statistical analyses of water quality data
- identified the major factors influencing the effectiveness of different types of buffer strips to guide land management decisions
- quantified the effect on land and timber resources of reserving buffer zones around streams
- quantified both the impact of wildfire on runoff and erosion from a natural soil surface, and soil recovery trends after the fire.

FUTURE CRC RESEARCH DIRECTIONS

This research project has contributed to the establishment of three new CRC projects:

Rehabilitation and management of riparian lands

The CRC for Catchment Hydrology now has a five-year (1995-2000) project on the role of riparian zones in modifying the physical and chemical nature of sediments. The project has established sites in four agricultural and ecological zones across Australia from the wet tropics of north Queensland to the mediterranean environments of southern Western Australia. This project forms part of the National Riparian Zone Program commissioned by the Land and Water Resources Research and Development Corporation.

Sediment sources and movement in forestry environments

The CRC for Catchment Hydrology now has established a forest hydrology program. Within this program, there is a three-year project (1996-1999) on sediment movement within forestry operations. This project is specifically focused on sediment redistribution as a result of intensive logging of native forest, and is also incorporating sediment tracing studies to quantify the contribution of sediment associated with logging to total stream sediment.

Controlling sediment and nutrient delivery from hillslopes to streams

In this new three-year project (1996-1999), the CRC is using rainfall simulator measurements, spatial modelling, and sediment tracers to develop and demonstrate a methodology to specify a catchment sediment budget. The budget will include the contributions of land surfaces, streambanks, and roads to stream sediment loads.

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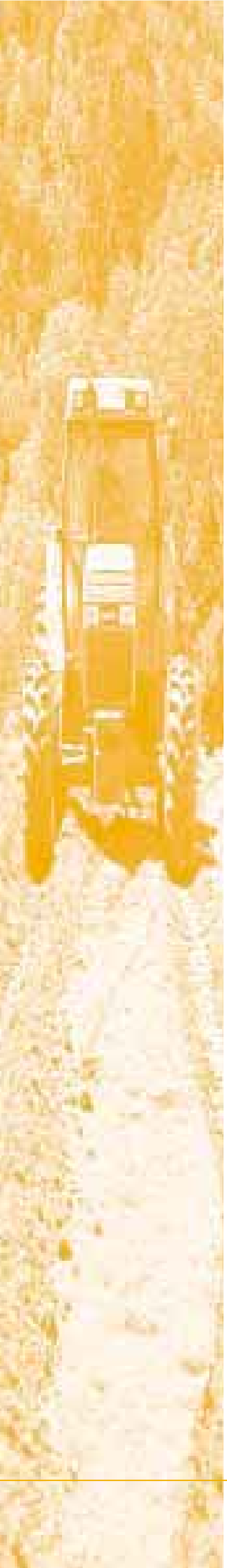

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CATCHMENT HYDROLOGY

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