# Appendix B – Literature Review

# 1 Contents

# 2 Document history and status

| Revision | Date issued | Reviewed by | Approved by | Date approved | Revision type |
|---|---|---|---|---|---|
| Draft | 21 July 2011 | D Lavery | D Lavery | 22 July 2011 | Practice Review |
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| **Printed:** | 4 September 2012 |
| **Last saved:** | 4 September 2012 12:27 PM |
| **File name:** | I:\VWES\Projects\VW08116\Deliverables\Reports\Lit review_v5.docx |
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| **Name of organisation:** | Murrumbidgee Catchment Management Authority |
| **Name of project:** | Actions for Clean Water Plan for the Upper Murrumbidgee Catchment |
| **Name of document:** | |
| **Document version:** | FINAL |
| **Project number:** | VW08116 |

# 3 Approach

The literature review identified erosion issues across the broader Upper Murrumbidgee catchment according to the following categories. The review was undertaken on a range of literature that has been collated during the early stages of the preparation of the Actions for Clean Water (ACWA) Plan. Many of the reports reviewed considered sites that are outside the nominated area of the ACWA Plan. This information has been retained in this review for completeness but will not be considered further.

The information collated during this literature review will be utilised to assist in the prioritisation of locations where management intervention may be undertaken to reduce the generation of suspended sediment and hence improve (lower) turbidity levels in the Upper Murrumbidgee River.

## 3.1 Location

A key objective of this literature review has been to identify the location of priority sites that are causing turbidity impacts. Where possible, the site or sub-catchment of a recognised source of sediment has been identified.

## 3.2 Pressure

This literature review focuses on the processes in the Upper Murrumbidgee catchment that are contributing to turbidity problems in the Murrumbidgee River and its tributaries. Based on the preliminary discussions with stakeholders and the literature itself, it is assumed that the primary cause of turbidity problems in this part of the catchment is erosion. Numerous drivers to this erosion are identified and examined in the literature, and are discussed in more detail for each source of information.

## 3.3 State

In almost all cases identified in the literature, sources of turbidity problems (i.e. eroding soils) are identified because they are already in a degraded state. The ‘state’ for most cases is therefore assumed to indicate environmental degradation. Erosion potential is identified at sites where active erosion has not yet commenced.

## 3.4 Response

Previous studies into erosion in the Upper Murrumbidgee have also provided advice on appropriate remediation techniques, and in some cases provided recommendations for erosion problems at specific sites. These have been noted for future reference as part of the Actions for Clean Water Plan.

# 4 Literature Reviewed

## 4.1 Murrumbidgee Catchment Action Plan

### Murrumbidgee Catchment Management Authority 2008

The Murrumbidgee Catchment Action Plan (CAP) sets out the management activities for the catchment over the next ten years. It sets targets for resource condition and catchment management activities, in line with state wide resource condition targets. The CAP describes catchment issues such as in-stream turbidity in terms of pressure, state and response. While it does not identify specific sites, the CAP sets out a Water Resource Condition Target to reduce suspended sediment levels in the Murrumbidgee River, and develops general Water Management Targets to achieve the Water Resource Condition Target.

The CAP details the State, Pressure and Response for in-stream turbidity in the Murrumbidgee catchment, an issue which is largely driven by land management regimes imposed since colonisation. These are (from MCMA 2008):

**State**

- The adequate flow of good-quality water is needed to support and maintain ecosystem health. Conversely healthy ecosystems generate and maintain flows of good quality water.
- Diffuse sources of pollution, such as soil and stream bank erosion, associated with catchment and riparian land management, are the dominant influence on water quality.
- Maintaining riparian vegetation is a key factor in reducing sediment loads within streams. Retaining or increasing riparian vegetation may not fully address sediment loads. In such cases structural control works may be needed.
- Broad level information on erosion 'hotspots' (i.e. across the upper or mid Murrumbidgee catchments) is limited. There has been isolated or sporadic research to identify hotspots which means in some localities the information is excellent and detailed but elsewhere it is incomplete or absent

**Pressure**

- Physical disturbance of ecosystems that reduces their filtration capacity.
- Clearing of riparian and catchment vegetation.
- Weed invasion that contributes to increased erosion.
- Stock management in and around water bodies.
- Erosion and sedimentation due to land management practices.
- Limited capacity of landholders to preserve or enhance the quality of riparian vegetation due to social and economic factors.

- Urban, industrial and rural residential development and expansion leading to reduced water quality.
- Diffuse and point source sediment inputs.
- Increased nutrient levels associated with sedimentation that lead to algal blooms, vegetation modification and in-stream habitat degradation.
- Changed flow regimes, river regulation and flow diversion.
- Introduction of exotic aquatic species, such as carp, that enhance in-stream sedimentation.
- Physical disturbance of ecosystems, reducing their filtration capacity.
- Stock management in and around water bodies.
- Erosion and sedimentation due to rural and urban development and practices.
- Drainage of wetlands or riparian zones for urban and rural development.
- Reduction in native vegetation cover.

**Response**

The Catchment Action Plan details a variety of suggested responses under Water Management Target 1 (Stream bank revegetation), which include:

- Establishment and protection of riparian vegetation.
- Prevention of in-stream sedimentation due to stream bank erosion.
- Recognition of the contribution landholders and the community play in stream bank management.
- Enhancement of community capacity and planning to enable investment in future works.

The responses associated with Water Management Target 2 (Structures for river bank stability) include:

- Establishment and protection of riparian vegetation in conjunction with structural control works.
- Prevention of erosion and sedimentation.
- Assessment of the trend in condition at selected sites to monitor change.
- Prediction, using modelling, of the changes in soil loss.
- In-stream monitoring at the catchment scale to monitor change in sedimentation.

## 4.2 Murrumbidgee Geomorphic Investigation for Works Prioritisation

### Earth Tech Engineering, 2006

This document summarises a catchment wide investigation undertaken on behalf of the Murrumbidgee CMA to determine the areas within the Murrumbidgee Catchment that have the potential to contribute high sediment and nutrient loads to the rivers. A desktop review of existing information was undertaken to indentify a list of priority sub-catchments, in terms of their potential

to generate sediment and nutrients, for further investigation. Field verification was then undertaken to confirm the priority sub-catchments and then to further prioritise reaches within the priority sub-catchments.

**Location**

The investigation considers the entire Murrumbidgee CMA area but excludes the component of the Murrumbidgee catchment within the ACT. The following sub-catchments were identified as being a priority in terms of their potential to contribute high sediment and nutrient loads to the rivers:

- Bombowlee/Brungle/Adjungbilly sub-catchment;
- Murrumbidgee, Gundagai to Berembed sub-catchment;
- Hillas sub-catchment;
- Adelong sub-catchment;
- Gilmore/Sandy sub-catchment;
- Murrumbidgee II sub-catchment;
- Goodradigbee sub-catchment;
- Bredbo sub-catchment; and
- Numarella (west) sub-catchment.

**State**

- Land use change because of European settlement across the catchment triggered historic, widespread channel incision and the delivery of enormous volumes of sediment to rivers. The resultant gully and stream network formed rapidly following clearing with most of the gully heads considered to have stabilised relatively quickly with channel walls remaining the major source of sediment to the rivers;
- In channel erosion (riverbank and gully) are the dominant sources of sediment in the upper and mid Murrumbidgee valley;
- Upstream tributaries are the major source of sediment to the Murrumbidgee River with sediment transport typically maximised during flood events;
- Sediment yields in the Murrumbidgee catchment are considered t be decreasing since the 1950's;
- Sections of the upper Murrumbidgee (downstream of Tantangara Reservoir and between Cooma and Bredbo) are predicted to have high rates of bank erosion and hillslope erosion is predicted to be high in the Monaro; and
- High densities of gullies exist in the Monaro (upstream of the ACT) as well as the Yass, Jugiong and Tarcutta catchments.

**Pressure:**

- Physical disturbance of ecosystems that reduces their filtration capacity.
- Clearing of riparian and catchment vegetation.
- Weed invasion that contributes to increased erosion.
- Stock management in and around water bodies.
- Erosion and sedimentation due to land management practices.
- Increased nutrient levels associated with sedimentation that lead to algal blooms, vegetation modification and in-stream habitat degradation.
- Changed flow regimes, river regulation and flow diversion.
- Introduction of exotic aquatic species, such as carp, that enhance in-stream sedimentation.
- Physical disturbance of ecosystems, reducing their filtration capacity.
- Stock management in and around water bodies.
- Erosion and sedimentation due to rural and urban development and practices.
- Drainage of wetlands or riparian zones for urban and rural development.
- Reduction in native vegetation cover.

**Response:**

The Geomorphic Investigation recommended the implementation of a range of management actions for each of the priority sub-catchments and reaches. Typically works were recommended based on their potential to reduce the delivery of sediment to the Murrumbidgee River. The types of riparian investment recommended included:

- Bed and bank stabilisation works;
- Revegetation and enhancement of remnant riparian vegetation;
- Weed control;
- Extraction of coarse sediment (sand extraction);
- Willow removal;
- Exclusion of domestic stock from riparian zones; and
- Gully stabilisation works.

## 4.3 Bredbo and the 'Bidgee: Management Strategies for the Murrumbidgee River and its Tributaries in the Bredbo District

Starr, B., Abbott, K., Ryan, J. and Goggin, J., 1997

This document sets out the drivers of erosion in the Bredbo district since colonisation, based on an examination of historical evidence. This includes the type and timing of changes to river channels in

this period. This analysis of the drivers of erosion is followed by a discussion of some of the key erosion processes, and recommended erosion management techniques for the Bredbo district. With a few exceptions, specific, high priority erosion sites within the Bredbo subcatchment are not identified.

**Location**

Bredbo district. Specific sources of erosion identified in the report include:

- The walls and floors of the major gullies between 'Billilingra' and the village of Bredbo that drain directly to the Murrumbidgee River.
- Active channels and banks in rivers and creeks in the district.

**State**

- Accelerated erosion had not commenced in 1840, but by 1851 there was extensive soil loss on the hillsides and in the drainage lines of the Bredbo district.
- These major changes are evident today as extended gully networks, which were largely established by the turn of the century.
- Since 1944, most of the gully networks have become naturally stabilised or are naturally stabilising.
- Gullies that are continuing to erode are losing soil from floor and walls, not by headward advance.
- A substantial sediment load is still contained within the Numeralla River, which has a continuous incised channel through the lower and middle reaches.
- With the exception of the reach just upstream of the confluence with the Murrumbidgee, the Numeralla has remained substantially unchanged since the channel incision that followed European settlement. Erosion that has occurred to the banks has been the result of localised failure or channel restriction with vegetation.
- The prime sources of sediment to the rivers in the Bredbo district are the active channels and banks of rivers and creeks, as identified, and the walls and floors of the major gullies between "Billilingra" and the village of Bredbo that drain directly to the Murrumbidgee River. Other gully networks are relatively inactive and/or deposit eroded material on footslopes or floodplains.
- Despite its general appearance, the Bredbo River has remained largely unchanged since European settlement. There has been little evident bank erosion and the bed of the river has not lowered.

**Pressure**

- The loss of groundcover from the combined effects of grazing and drought, plus the disturbance of prone areas by cloven-hoofed animals, were the main drivers for early erosion.
- Localised storms and rainfall events produced a series of floods that triggered catastrophic significant gully erosion.

- Although present stocking numbers are much higher than those in the 1870s (the active erosion period), soil loss from hillslopes continues to decline.

**Response**

The report makes the following management recommendations for various parts of the catchment:

- Management of the lower Numeralla should continue on the basis of prevention of channel restriction or flow diversion by in-stream vegetation. Management should include enhancement of bank vegetation to aid in preventing erosion that may occur during flood events.
- It is recommended that works programs are based on downstream benefits and target areas identified as prime sediment sources.

## 4.4 Budgeting for 'Bidgee Banks

### Starr, B., 2000

This report provides management recommendations for the 'Bidgee Banks project, a two year project that invested $1.3 million in addressing nutrient loads and vegetation decline in the riparian zones of the upper- and mid-Murrumbidgee catchment. This included addressing streambank erosion hotspots and the conservation of high value remnant riparian vegetation. The report also provides a sediment budget to understand the processes underway in the Murrumbidgee catchment.

**Location**

Erosion hotspots identified in the report include:

*Tantangara Dam to Numerella River*

- Yaouk Creek/Sams Creek (reference Yaouk 655343), and headcuts along Bradleys Creek to the east.
- Murrumbidgee River at the exit to Cooma Gorge to the confluence with the Numerella River.

*Murrumbidgee to Bredbo and Bredbo Subcatchment*

- Section of bank upstream of Billilingra Road crossing (reference Murrumbucca 923105).
- Major gully immediately upstream of Billilingra Gorge (reference Bredbo 922143).
- Lower reaches of Buchan Creek (tributary of the Bredbo River; reference 999143).
- Wangrah Creek, as the channel widens.
- A major deposition of bedload occurred in the Murrumbidgee River upstream of Billilingra Gorge in the early 1920s. Substantial erosion has occurred since, with bed erosion since 1944 relocating the channel to the centre of the river and reducing bank erosion.

*Googong Dam Subcatchment*

- Major gully in Tinderry Nature Reserve.
- Holdens Creek (reference Williamsdale 007625) and the unnamed creek draining the KT Park area (reference Williamsdale 024668).

*Jerrabomberra Creek Subcatchment*

- Tralee Station, immediately downstream of Jerrabomberra urban area (reference Tuggeranong 986815).

**State and Pressure**

Sources of fine sediments in the catchment are identified according to erosion type (sheet and rill erosion, hillslope depression gullies, valley floor channels – deposition and erosion, streambank erosion, main channel deposition and sediment immobilisation, and main channel bed erosion.

The report notes recent changes in the upper- and mid-catchment due to erosion processes, and explains the geological and hydrological regimes that are present in these environments. This provides a strong background resource for erosion management works.

**Response**

The report provides general guidance on appropriate (and inappropriate) options for treating and preventing erosion based on erosion type. These are summarised below:

*Hillslope Depression Gullies*

- Appropriate works: fencing for stock exclusion/managed grazing; sowing/planting of gully floors; sowing/mulching of eroding gully fill; and minor drop structures.
- Inappropriate works: major repair earthworks or ripping; and new gully filling (i.e. rehabilitation).

*Valley Floor Channels*

- Appropriate works: fencing for permanent stock exclusion; planting to increase bed stability; and minor drop structures.
- Inappropriate works: bank shaping/batters; and in-channel tree planting.

*Streambank Erosion*

- Appropriate works: freeform rock armouring for bank toe protection; rock sausages and planting for bank toe protection/groynes; and bank toe planting.
- Inappropriate works: exclusion fencing (unless stock are the main cause of erosion); and bank shaping/batters.

*Main Channel Sediment Deposition and Immobilisation*

- Fencing for stock control and vegetation enhancement are considered appropriate for in-channel vegetated deposits.

*Streambed Erosion – Main Channels*

- No works are considered appropriate/cost effective, due to the high cost of works to main channel streams that are undergoing incision.

## 4.5 Sustainable Water Action Management Project: Strategy and Action Plan

Environment ACT, 2000

The Sustainable Water Action Management Project (SWAMP) was a Natural Heritage trust-funded project that sought to improve stream health in an area centred on Queanbeyan that covered parts of the ACT and NSW. The project largely focused on activities that would improve in-stream water quality within the project area. While a number of these actions targeted biological and chemical sources of poor water quality, the project also addressed land and riparian management options for improving turbidity.

**Location and State**

- Sources of sediment identified in the project area's subcatchments are listed below:
- Woolshed Creek catchment experiences collapsing creek banks and in-channel erosion during significant erosion events; there is active gully erosion and sediment yielded from agricultural land.
- Reedy Creek experiences erosion within the stream channel and from creek banks.
- Molonglo River carrying sediment from within the Molonglo catchment from in stream erosion.
- More than 80% of the sediment yield in Jerrabomberra Creek is estimated to come from the creek and gullies.

**Pressure**

Pressures are only identified briefly in the report, and consist of:

- The grazing of riparian zones leading to erosion and poor stream water quality.
- The construction of structures, from culverts and road crossings through to weirs and dams, as impeding the movement of sediment and altering flow regimes to the detriment of water quality.

**Response**

- Woolshed Creek – revegetation projects on individual properties; soil conservation and erosion control at Majura Training Area; road and track drainage, refurbishment and decommissioning works for erosion control; and strategic fencing of Woolshed Creek.
- Reedy Creek – stabilising the creek and adjacent land; off-stream stock water supply, revegetation and fencing; development of revegetation species list.
- Molonglo River – road and track drainage, refurbishment and decommissioning works for erosion control; remediation of upper sections of the river.
- Jerrabomberra Creek – rehabilitation of the creek to address significant erosion and enhance bank stability.

## 4.6 A Reconnaissance of Trends in the Condition of Streams in the Australian Capital Territory

Starr, B., 2000

The purpose of this report was to provide a sound basis on which to set priorities for the ACT Riparian Restoration Program. The aim of this program was to protect rivers, creeks and major valley floor channels from further degradation by targeting erosion sites and improving the general state of riparian vegetation.

**Location**

This report considered all major waterways in the ACT including the following major waterways and their tributaries:

- Murrumbidgee River;
- Paddys River;
- Woolshed Creek;
- Tuggeranong Creek;
- Freshford Creek;
- Naas River;
- Gudgenby River;
- Cotter River; and
- Molonglo River.

**State**

The report identifies two common changes to the waterways of the ACT that have occurred since 1944 – bed incision and an increase in riparian zone vegetation.

Bed incision is noted as occurring across a full range of channels with coarse bedload being stripped from larger streams and the incision of smaller channels generating finer sediments.

The increase in riparian vegetation is identified as consisting of both native an introduced species. Introduced species becoming more abundant include blackberry and several species of seeding willows.

**Pressure**

The report identifies a number of pressures that have contributed to an overall decline in the condition of waterways in the ACT since 1944. These include:

- Increased abundance of exotic vegetation (willow, poplar, blackberry) in the riparian zone of many waterways in the study area;
- Unrestricted access for domestic livestock to the riparian zone of many waterways in the study area; and

- Decline in the diversity of native vegetation in the riparian zone of many of the waterways in the study area as a result of the above.

**Response**

Priority Management Recommendations were provided for a total of 35 sites within the study area. For some o f the sites the recommendations related to the maintenance of existing conditions. At the following 10 sites specific management interventions were recommended:

- Freshford Creek (Murrumbidgee River) – Monitor upstream section of the waterway that has been infilled with imported material;
- Freshford Gully (Freshford Creek) – Consider works (construction of drop structure) to ameliorate erosion in major active gully that has been caused by diversion of flow;
- Gudgenby Creek (Naas River) – Fencing and revegetation with suitable native species to address issues of bed incision immediately upstream of Naas River confluence;
- Gudgenby River upstream of Naas confluence – control seeding willows;
- Gudgenby River downstream of Naas confluence – control seeding willows;
- Honeysuckle Creek (Gudgenby River) – Fencing and revegetation with suitable native species;
- Naas River (Gudgenby River) – control seeding willows;
- Naas River (Gudgenby River) – fencing of Billys Creek and rock armouring of eroding banks adjacent to bridge abutments;
- Naas River (Gudgenby River) – fencing of several gullies to control stock movement and access; and
- Spring Station Creek (Murrumbidgee River) – construct grade control structures on two major headcuts on the waterway.

## 4.7 Soil Erosion, Phosphorus & Dryland Salinity in the Upper Murrumbidgee: Past Change & Current Findings

### Starr, B., Wasson, R. and Caitcheon, G., 1999

This report aims to provide background information for managing the three major concerns of the Upper Murrumbidgee catchment: erosion, phosphorus and dryland salinity. The report uses research based on historic evidence to suggest that erosion in this part of the catchment, particularly deeply incised hillside gullies, is not a recent phenomenon and is the result of more active erosion in the 19$^{th}$ century. It provides in detail the causes of historic and current erosion, erosion processes in the Upper Murrumbidgee, and major channel changes to rivers such as the Numerella River and Murrumbidgee River. It goes on to provide comments on appropriate management responses for dealing with these threats.

**Location**

As mentioned above, a key argument of this report is that the main period of gully and channel

erosion occurred between initial settlement of the Upper Murrumbidgee and the late 19th century. The sites of active erosion identified in the report are limited, consisting of:

- Some erosion still occurring in Wangrah Creek and some of its tributaries.
- Major incision near the headwaters of Burra Creek (from Eyles 1977).
- The full length of the main channel of Burra Creek was considered to be actively eroding (Eyles 1977). Starr et al (1990) showed that Burra and Jerrabomberra Creeks were continuing to erode, but only at a few locations.
- Active erosion in the Queanbeyan River catchment is limited to a few locations on several creeks.
- Tinderry Creek has experienced bed lowering and bank erosion following major bushfires in the 1950s.
- Some channel erosion is still occurring in creeks in the Michelago area, including the Michelago Creek, and bed erosion in Margarets Creek and Tea Tree Creek.

**State**

A key assertion of the report is that despite the numerous gullies and changes to river channels, the main gully and channel erosion phase occurred in the mid-late 19th century. Aerial photography has been used to determine rates of erosion in the 20th century, with imagery from 1944 compared with later photographs (as early as 1968). These photographs show that gully networks in the Upper Murrumbidgee had reached their headward limits by 1944. Current active erosion is therefore thought to be far below rates seen in the late 19th century, where Wasson et al (1998) estimated sediment production was 200 times the pre-colonisation levels, compared with a current rate of 17 times pre-colonisation levels.

**Pressure**

The report identifies a number of pressures that have contributed to erosion since colonisation. Clearing by hand and by machine has occurred in the Upper Murrumbidgee in the 19th an 20th centuries, and is frequently identified as a cause of erosion. The report, however, largely discounts the clearing of trees as a cause of the main erosion phase in the 19th century. It stops short of the same conclusions about the current impact of the loss of tree cover, noting that clearing in some areas leads to erosion, while it does not in others. Site susceptibility and the degree of disturbance are identified as the key factors in this case.

Overgrazing and soil disturbance by sheep, cattle and horses are identified as a significant cause of initial erosion, providing that there were heavy rains before the land recovered. Surface flows along stock tracks would have led to channel erosion, leading the report to conclude that stock hooves were likely a leading cause of erosion. Changes to farming practices (from shepherding to fenced paddocks) meant that the impact of stock was spread over a paddock, rather than concentrated grazing in one area. This meant that stock were no longer concentrated on paths.

Early roads in the region were constructed on the lowest possible gradient. However, gullies are often present at watercourse crossings. As motorised transport became more widespread, some roads became steeper and lined with gullies and becoming a significant area of work for the NSW Soil Conservation Service.

The contribution of cropping and fire to erosion in the Upper Murrumbidgee are not immediately clear in the report, but appear to be limited. However, channel incision, diversion and meandering have been observed in Tinderry Creek as a result of a fire in 1957.

Burrowing and grazing by rabbits and hares are thought to be a significant cause of erosion as their numbers increased in the 20th century. Weeds are another factor that continue to be an issue in the Upper Murrumbidgee, with the targeting of species such as Serrated Tussock and African Lovegrass meaning that soil is exposed once non-selective herbicides have been applied. Willows are also issue in this part of the catchment, leading to the erosion of river banks as willows choke existing channels.

**Response**

The interrelationship between sediment and phosphorus in aquatic ecosystems means that erosion and phosphorus should be addressed though soil conservation. This is because 90% of the phosphorus entering aquatic ecosystems thought to be carried by sediments. The following management recommendations are made according to the land type:

- Hillslopes – sheet and rill erosion on hillslopes is not considered to be a significant source of sediment, with no specific management responses recommended. The report does, however, note that 'limiting the spread of weeds is important in reducing the area of land susceptible to sheet and rill erosion.'
- Gullies – as previously asserted, most of the incisions in the Upper Murrumbidgee occurred in the 19th century. Many gullies are no longer active, are rehabilitating naturally and are no longer significant sources of sediment in the catchment. Works are not considered to be worthwhile unless a gully system is still eroding and it is connected to a continuous channel system. The report recommends the management of incised channels to reduce the amount of sediment being produced and to entrap sediment moving down the catchment from upstream, an approach that is considered to be of much greater benefit than hillslope erosion prevention measures. Coarse gravels and sands are gradually moving downstream towards Burrinjuck Dam and require management to protect in-stream habitats. The protection of vegetation on valley floors is also considered to be of high importance, as maintaining this cover protects it from future incision.
- Rivers and Creeks – active channel change is continuing, and catastrophic channel change is expected to occur again in the future. Works at high risk sites are recommended. Structural armouring and bank revegetation are specifically recommended for erosion control works in this instance.

## 4.8 The State of Streams in the Upper Murrumbidgee Catchment

### Bredbo Landcare Group and Numerella Landcare Group 1993

This report briefly details the existing state and erosions pressures in the Upper Murrumbidgee. Like other literature reviewed here, it also reviews historical documentation and asserts that the gully networks in this part of the catchment are a consequence of erosion in the 19th century and are no longer active.

**Location**

The report covers Jerrabomberra Creek, Tinderry Creek, 'Ti Tree Creek' (Numerella) and the 'Bredbo gullies'. While sites of historical erosion are presented, the report does not detail any sites of currently active erosion.

**State**

The report notes in general terms that while hillslope and incisions have largely stabilised, there is ongoing erosion from the beds and banks of major creeks and rivers in this part of the catchment. Sites of significant erosion which have now stabilised are presented as examples of the erosion that the Upper Murrumbidgee has experienced.

**Pressure**

Erosion pressures are referred to generally, with the cause in this case identified as erosion that commenced under previous land and stream management regimes, along with current land management practices.

**Response**

The report notes that historical efforts at erosion control consisted of extensive tree planting, a treatment which it suggests was successful.

## 4.9 Bidgee Banks: Monitoring & Evaluation in the Upper Catchment

### Patmore, S. and Davey, A., 2004

This report from the University of Canberra's School of Resource, Environmental and Heritage Sciences evaluates the implementation and effects of the Bidgee Banks project, which aimed to conserve riparian vegetation and target streambank erosion through 104 individual projects. Approximately 38 projects were surveyed as part of the monitoring and evaluation component of Bidgee Banks. The report presents the results of the surveys and summarises the results of the projects, along with lessons learned and a series of recommendations for future projects.

**Location**

The report does not provide location-specific information about active erosion in the upper Murrumbidgee.

**State**

This monitoring and evaluation report does not detail the current condition of the upper catchment or sites within it, other than recording how many of the funded works were completed. These were 59% for fencing and planting works, and 83% for earthworks, noting that this report was prepared before some projects were able to be completed.

**Pressure**

The report does not provide information on erosion pressures in the Upper Murrumbidgee.

**Response**

The report provides a number of conclusions and recommendations for the erosion control activities used. Drought and damage from pests (including native species) had the biggest impacts on the success of planting activities, such as the rehabilitation of eroding sites. The report recommends that:

- The timing of planting should avoid hot and dry conditions, with individual 2-3 year plans for properties that accounted for seasonal conditions considered desirable.
- Monitoring and survey data collection should be conducted as part of the standard project administration, rather than as a separate task that doubles-up on the required field work.
- The physical function of activities needs to account for their ecological function as well e.g. 'dense linear rows of uniformly aged trees are not necessarily a true reflection of natural riparian habitat.' Future projects should prioritise broad (rather than narrow) strips of planting with a mix of understorey species and trees.
- Funding should be sought for follow up studies of about five years for a period of at least 20-25 years.
- More explicit and integrated planning for arrangements governing landholder agreements, data capture and analysis.

## 4.10 Techniques for Targeting Protection and Rehabilitation of Riparian Vegetation In the Middle and Upper Murrumbidgee Catchment

Wilkinson, S., Jansen, A., Watts, R., Read, A. and Miller, T., 2004

This report describes the application of SedNet model and Rapid Appraisal of Riparian Condition in the middle and upper Murrumbidgee Catchment. The intent of the study is to assist the Murrumbidgee Catchment Management Authority in prioritising vegetation conservation and

erosion control efforts. The report outlines both the inputs to the model, along with the outputs from this modelling.

**Location**
The report does not specifically identify individual sites that require rehabilitation, although it does provide maps of the middle and upper catchment that show where the model predicts erosion is occurring. The relevant maps are provided in Attachment A.

**State**
The model provides the following results for identifying the supply of sediment in the study area:

- Hillslope suspended supply: 19%
- Gully suspended supply: 12%
- Gully bedload supply: 24%
- Riverbank suspended supply: 23%
- Riverbank bedload supply: 23%

Low levels of riparian vegetation in the middle and upper catchment results in high levels of predicted bank erosion, with high hillslope erosion expected in the intensively farmed tableland areas and the Monaro.

**Pressure**
Erosion pressures in the Upper Murrumbidgee are not discussed in detail in this report. The report operates on the assumption that a lack of riparian vegetation is a prime cause of erosion in this part of the catchment.

**Response**
The report concludes that management priorities for the middle and upper Murrumbidgee should focus on reducing the supply of suspended sediment protecting and restoring riparian vegetation to address bank and gully erosion. The highest risk areas are considered by this report to be banks with the greatest erosion hazard, and areas with the greatest density of gully networks.

## 4.11 Soil Erosion on Scottsdale: Assessment and Remediation

### Soil and Land Conservation Consulting, 2008

This report details the extent of erosion at Scottsdale, a property recently acquired by Bush Heritage Australia 4 km north of Bredbo. It provides an overview of the historical erosion in this part of the catchment, and the erosion processes present on the property. Four key strategies are identified for managing erosion at the site.

**Location**
The following sites are identified as high priorities for erosion control measures (and are mapped in the report):

- Incision site on in-stream wetland;
- Severely eroded track, plateau south end;

- Track drainage, plateau north end;
- Active gully head near boundary track; and
- Track drainage, railway boundary track.

**State**

Scottsdale, like the rest of the Bredbo area, has been heavily affected by erosion. There are extensive gully networks and hillslope erosion, although the report notes that the rate of erosion is considerably less than during the early colonial period. On the hillslopes, there has an absence of topsoil, exposed tree roots and localised patches of minimal or no groundcover. However, recovery of groundcover (African Lovegrass in this case) now means that hillslope erosion is no longer a major problem.

Despite the extent of gully networks on the property (estimated at 2.4 km/km$^2$ for the eastern part of the property, where gullies are located), the present level of active gully erosion is considered to be low. No gullies appear to eroding headwards, there is little slumping or undercutting of gully walls, there is well established grass cover along gully walls and relatively little sediment is being transported along the gully network.

Gungoandra Creek flows through the property, 0.87 km of which is classified as erosional channel in the report. The remaining 4.25 km of the Creek that flows through Scottsdale is classified as an in-stream wetland that acts as a sediment trap.

There are also a number of sites on the property's tracks that require intervention. A total of 0.9 km of tracks at Scottsdale are considered to need work to maintain their serviceability and to minimise their impact of water quality.

**Pressure**

The report notes that grazing and cropping following colonisation is largely responsible for the degraded soil structures in the area. While this rate of erosion has since peaked, sediment from channel incision in the area is still moving downstream, with significant deposits in trunk streams.

**Response**

The report proposes four key strategies to control erosion at Scottsdale, which include:

- Managing groundcover – maintain minimum 70% groundcover, weed control activities that do not expose soil for extended periods, and repair localised patches of bare ground.
- Protect Gungoandra Creek in-stream wetland – define its natural functions, consider repairing the incision point using a rock flume, and consider pig control.
- Promote long-term stability of the gully erosion network – construct in-stream sediment dams, construct diversion bank around active gully head at railway culvert, other gully stabilisation as required, continue to prevent stock access, and revegetate gullies with trees and shrubs over the long term.
- Control track erosion – repair or close the plateau access track at the southern end, construct drainage diversion banks on the plateau access track and along the railway boundary, and ongoing, routine maintenance of the track system.

## 4.12 The Numerella: River of Change

Starr, B., c. 1995

This manual sets out the recent changes in the Numerella Valley, identifies the drivers for these changes and sets out recommendations for the management of the river corridor. Like a number of other reports on erosion in the Upper Murrumbidgee, the manual outlines the historical reasons for erosion in this part of the catchment, the stream behaviour and processes behind it, and management guidelines. One of the drivers for the preparation of this manual was the July 1991 floods, which removed large quantities of sediment and soils from the catchment.

**Location**

A number of sites are identified throughout the report, particular those at which extensive historical erosion has occurred. The report breaks the Numerella River down into 'RiverCare' sections, although a number of the plans for these sections are missing. This may be a valuable resource in prioritising works, providing a complete copy of the report can be obtained and information collated on the extent of the sites that have since been treated.

**State**

The report details the extensive hillslope erosion prevalent in this part of the catchment, including the development of gully networks and sheet erosion. It goes on the document to relative recovery of this landscape in the years since 1944.

The changes to the valley floor are also discussed, including the relative stability of the lower section of river, the dynamic nature of the upstream section, and bank erosion along vertical banks on the outside of most meander bends.

**Pressure**

The report outlines the impacts of European activities on the catchment, identifying grazing, clearing, cropping and gold mining as land management changes that placed pressure on the catchment and river. Stream behaviour is also discussed in detail, with stream dynamics receiving significant attention. Processes such as bank erosion, energy distribution, meandering, bed lowering and sediment slugs are all examined as factors contributing to changes in river alignment.

**Response**

The manual provides general advice for managing erosion and waterways, along with specific recommendation for each of the RiverCare sections. The management principles are:

- Choose the most appropriate method for each location;
- Manage streams as a continuous, linked system;
- Do not try to control, or substantially alter the characteristics of a river;
- Treat the causes, not just the symptoms of erosion; and
- Be aware of other rivers uses and values.

General principles from the manual include:

- Limit the use of exotics to the outside of meander bends, or other areas where undercutting is occurring.

- Do not plant any trees or shrubs on sand or gravel bars on the inside of meander bends.
- Do not plant large trees on banks that are steeper than 1:4.
- Aim to progressively replace exotics.
- Promote the growth of sedges, reeds, rushes etc.

## 4.13 NSW Diffuse Source Water Pollution Strategy

### NSW Department of Environment and Climate Change. 2009

The *NSW Diffuse Source Water Pollution Strategy* (DSWPS) provides a framework for coordinating efforts in reducing diffuse source water pollution and establishing a process for sharing information and fostering partnerships to maximise pollution management benefits. A key component of the strategy is the involvement of key natural resource management stakeholders. The DSWPS also recognises that NSW has a network of rivers and waterways which provide the foundation to many local communities, environmentally, socially and economically. Therefore the health and well-being of these waterways is fundamental to the health of the community and environment. The DSWPS identifies diffuse sources of pollution such as run-off from rainfall and storms as being a major contributor to pollutant loads in NSW waterways.

The DSWPS has acknowledged that the 'historic' approach to managing water pollution, which has predominantly involved focusing efforts on treating the point source of water pollution; is very limiting and does not deal with the issue at the broader scale.

The long-term intent of the DSWPS is to demonstrate the management actions that will contribute to the achievement of the State-wide NRM targets, agreed by Government and presented in the NSW State Plan.

The DSWPS identifies the State, Pressure and Response for diffuse source water pollution throughout the state of NSW as being a consequence of a variety of factors, including previous land-use and planning, environmental legislation, policies and procedures. These are (from DECC 2009):

**State**

- Diffuse source water pollution is the contamination of water bodies by pollutants arising from a multitude of diverse urban and rural land use activities across a catchment, rather than from a discrete point source.

**Pressure**

- There are three priority diffuse water pollutants which have been identified across NSW, they are: sediments, nutrients and pathogens – which can arise from a multitude of sources.
- The key issues affecting rivers in NSW are land use changes that result in elevated loads of nutrients and suspended sediment, changes to the hydrological regime, and loss of riparian vegetation. In addition, the scale of land use activities is an important factor in how diffuse source water pollution impacts on the environment.

**Response**

- A priority action plan (PAP) has been developed as a component of the DSWPS and is the framework that sets out the State-level priority actions and commitments to improving surface and groundwater quality.
- The DSWPS and PAP aim to influence and focus investment by agencies to achieve synergies form their existing resources, and to support proposals for investment from other NRM programs, such as the Commonwealth Government's Caring for our Country and the NSW Environmental Trust.
- Importantly the DSWPS promotes partnerships, provides a guide for investment, and provides a means to share information on projects and their outcomes across the State.

## 4.14 ACT Erosion Potential Mapping Report

### URS for ACT Parks, Conservation and Lands., 2009

This report utilised a GIS based methodology to consider soil erosion potential in the ACT particularly in terms of ongoing fire management. The Revised Universal Soil Loss Equation (RUSLE) was used to estimate erosion potential for the entire ACT and for the area immediately surrounding the Googong Dam in NSW.

The Revised Universal Soil Loss Equation (RUSLE) is an empirically based equation that is used to compute sheet and rill erosion. The equation factors represent the four major factors that contribute to erosion, namely climate, soil erodibility, topography, and land cover. The equation is:

***A*** (tons/acre*year) = ***R*K*L*S*C*P***

A = average annual soil loss caused by sheet and rill erosion [t $ha^{-1}$ $y^{-1}$].

R = rainfall erosivity factor [MJ mm $h^{-1}$ $ha^{-1}$ $y^{-1}$].

K= soil erodibility factor [t ha h $ha^{-1}$ $MJ^{-1}$ $mm^{-1}$].

LS = slope length factor (dimensionless).

C = land cover and management factor (dimensionless, ranging 0.001 to 1).

P = support practice factor (dimensionless, typically ranging 0 to 1).

The report noted that any soil loss of greater than 35 tonnes/hectare/year would constitute a serious erosion problem. The report calculated the potential soil loss per hectare per year for the entire project area with 97% of the project area have potential soil loss rates of less than 15 tonnes/hectare/year.

The report then compared a range of fire fuel management options in terms of their impact on potential soil loss. The final project outputs were a series of maps that presented the change in potential soil erosion once a particular fuel management activity was applied.

**State**

- Soil erosion rates vary across the project area according to the equation:

***A*** (tons/acre*year) = ***R*K*L*S*C*P***

Where: **A** = average annual soil loss caused by sheet and rill erosion [t ha $^{-1}$ y $^{-1}$], **R** = rainfall erosivity factor [MJ mm h$^{-1}$ ha$^{-1}$ y$^{-1}$], **K**= soil erodibility factor [t ha h ha$^{-1}$ MJ $^{-1}$ mm$^{-1}$]

**LS** = slope length factor (dimensionless), **C** = land cover and management factor (dimensionless, ranging 0.001 to 1) and **P** = support practice factor (dimensionless, typically ranging 0 to 1).

**Pressure**

- Differing fire fuel management activities will each have a differing impact on soil erosion rates.
- A range of mitigation strategies should be employed to mitigate the impact of fuel management activities on soil erosion rates.

**Response**

- Future fire fuel management activities should be mindful of their potential impact on soil erosion rates and should be undertaken in conjunction with an appropriate erosion mitigation strategy.

# 5 Other Documents Reviewed

The following documents were examined as part of this literature review, but yielded little information that was relevant to identifying or managing erosion in the Upper Murrumbidgee.

## 5.1 Water Quality Data

As part of the literature review a high level review was undertaken of water quality data held by ActewAGL and by the ACT Government (including Waterwatch data). The primary water quality parameter that was considered was turbidity which was available from a significant number of locations within the ACWA Plan area.

Given that the data had been collected by a range of organisations for a variety of purposes there was a significant variance in the frequency of sampling. Sampling had occurred as frequently as weekly or as infrequently as monthly. Some sites had gaps in the data record and others had changed sampling frequency over the duration of the data records.

This inherent inconsistency in the data made it very difficult to draw strong conclusions however a number of key trends in the data were clearly visible:

- Turbidity levels in the Murrumbidgee River and its tributaries is variable with high turbidity events being recorded against relatively constant background turbidity levels;
- Turbidity levels in the Murrumbidgee River typically increase downstream;
- Given the episodic nature of high turbidity events the historic frequency of water quality sampling is unlikely to have captured all episodes of poor quality water in the Murrumbidgee River; and
- Given the distribution of water quality sampling sites across the catchment it is not possible to identify the locations of all potential sources of turbidity.

## 5.2 River Styles® in the Hunter Catchment
### Cook, N. and Schneider, G., 2006

The River Styles® framework appears to be a valuable tool in understanding geomorphic processes and assessing erosion risks. This report details the application of the framework to the Hunter Catchment and provides information on components of the framework.

## 5.3 Murray–Darling Basin Rivers: Ecosystem Health Check, 2004–2007
### Murray-Darling Basin Commission, 2008

This report, as part of the Sustainable Rivers Audit program, details findings on the health of the Basin's rivers according to hydrology, macroinvertebrate and fish indicators. While it reports on the

health of the Murrumbidgee catchment, it does not, provide information on erosion or management options in the Upper Murrumbidgee.

## 5.4 Riverine Assessment Project - High Conservation Values Mapping

Sinclair Knight Merz, 2005

This report details the application of high conservation value criteria in the interim Murrumbidgee Catchment. It does not identify erosion sites or management options in the process, although the high conservation values identified could be used to prioritise sites that are threatened by erosion processes.

## 5.5 The Effects of Phosphorus Removal from Cooma Sewage Treatment Works on Downstream Aquatic Environments: Interim Report

Dudgeon, S., 1995

Although the focus of this report is on the impact of the sewage treatment plant at Cooma, it does note that Cooma Creek produced the highest observed turbidity levels of the sites monitored. This was in response to a high rainfall event. The data also offers a potential for monitoring erosion by proxy, given that phosphorus concentrations from diffuse sources (i.e. not sewage treatment plants) depend upon the movement of sediment.

## 5.6 Utilisation and Protection of the Murrumbidgee River System in the ACT

National Capital Development Commission, 1981

This report largely focuses on the impacts of urban development on the Murrumbidgee River and only mentions turbidity in passing.

## 5.7 Willow Management—A Strategy for the Upper Murrumbidgee Catchment

Upper Murrumbidgee Catchment Coordinating Committee, 2010

This strategy sets out the UMCCC's priorities for controlling willows in the upper part of the catchment, including mapping and classification of willow extent by subcatchment. While specific sites where willows are contributing to erosion are not identified, the mapping could be used as proxy indicator for identifying sites that are potentially at a high risk of in-stream erosion.

## 5.8 Willow Management Strategy for the Upper Murrumbidgee Catchment

ACT Environment Advisory Committee and Upper Murrumbidgee Catchment Coordinating Committee 1998

This strategy is superseded by the 2010 Willow Management Strategy. The 1998 strategy only provides general guidance on the impacts of willows on erosion.

## 5.9 Tertiary Lake Bunyan, Northern Monaro, NSW, Parts I & II

Taylor, G., and Walker. P., 1986

These papers outline the geology of the Bunyan formation, providing background information for understanding erosion in the region.