PART B:
TECHNICAL REPORT

1 Introduction

Part B of the ACWA Plan is presented as a complementary technical document that supports the outcomes of the actions presented in Part A. As part of this project, extensive investigation of point sources of turbidity generation was undertaken. Part B is intended as supplementary material that details the investigation leading to the recommendations presented in Part A of the ACWA Plan.

2 Catchment condition

The ACWA Plan area is approximately 6,400 km^2 and extends from just north of Canberra in the ACT south towards Cooma and then west past Adaminaby to the headwaters of the Murrumbidgee system above Tantangara Reservoir. The catchment is large and diverse with a range of factors potentially contributing to the generation of turbidity. Key factors are described in the following sections.

2.1 Soils & Geology

Soil types throughout the ACWA Plan area are variable dependent upon the underlying geology from which they have been derived. From a regional geological setting the Plan area is in the eastern section of the Lachlan Fold Belt. This area is comprised of a series of north-south trending igneous, sedimentary and metamorphic rocks, which have been folded and faulted in association with regional deformation.

The weathering of this parent material has produced soils with a range of different physical and chemical properties. Processes such as the erosion and redistribution of weathered material have also contributed to the complex and varied nature of soil materials and landscapes.

The broader geological units can be broken down as follows:

- Cambrian to Ordovician – Suites of metamorphics and marine sediments located in a north south trending unit from Nimmitabel to Michelago, Cooma to Gudgenby and Eucumbene to Tantangara.
- Silurian – Volcanics and sedimentary rocks consisting of felsic volcanics, sandstones, shales, mudstones and limestones. These occur in north south trending units, with the most extensive distribution between Cooma and Colinton.
- Silurian to Devonian – Granite and Granodiorite plutons. These occur along the Great Dividing Range to the east of the area and to the west of the Murrumbidgee River, from Cooma to the confluence with the Cotter River.
- Cenozoic – Basalts dominate the areas east, south and west of Cooma, with minor distribution present to the north.

The structural geology includes a complex series of north south trending faults, which influence the topography and landscapes of the ACWA Plan area. Many of the ridge systems occur in conjunction with regional fault lines and the Murrumbidgee River trends along the one of these from the north of Cooma to Cotter Dam.

This complex relationship of slope, physiography and rock type has controlled the distribution of soils in the area, with soils associated with the Ordovician rocks tending to be finer grained sodic/dispersive, and soils with the higher slopes of the granite bodies lighter textured. Low positions in the landscape also generally reflect heavier soils.

The vulnerability of soils to erosion has been mapped by the NSW Office of Environment and Heritage via the Soil Landscape approach. Soil Regolith Stability is a simple scheme based on Soil Landscape Data which classifies soils in terms of both their potential to release sediment and the potential for sediment to move long distances. This classification system is a useful predictor of how likely soil is to cause turbidly in receiving waters.

The Soil Regolith Classification is based on the following matrix giving four regolith classes with each Soil Landscape Component being allocated to a Soil Regolith Stability Class (Table 10).

Table 10 Soil Regolith stability classification

		Potential for Sediment to Move Long Distances	
		LOW (Sediment is Coarse)	**HIGH** (Sediment is Fine)
Potential for Soil to Release Sediment	**HIGH** (Low Soil Stability)	**R2**	**R4**
	LOW (High Soil Stability)	**R1**	**R3**

All areas of the ACWA Plan have been assigned to one of the four soil regolith classes and have been allocated a regolith stability classification. A regolith stability classification consists of a dominant class and up to three sub-dominant classes. Soils of Regolith Class R4 are of the greatest interest because soils of this class have a high potential to release fine sediment which could contribute to downstream turbidity. Of secondary interest are Regolith Class R3 soils (dominant class) that contain sub-dominant R4 soils. Soils of these two types are mapped in Figure 8.

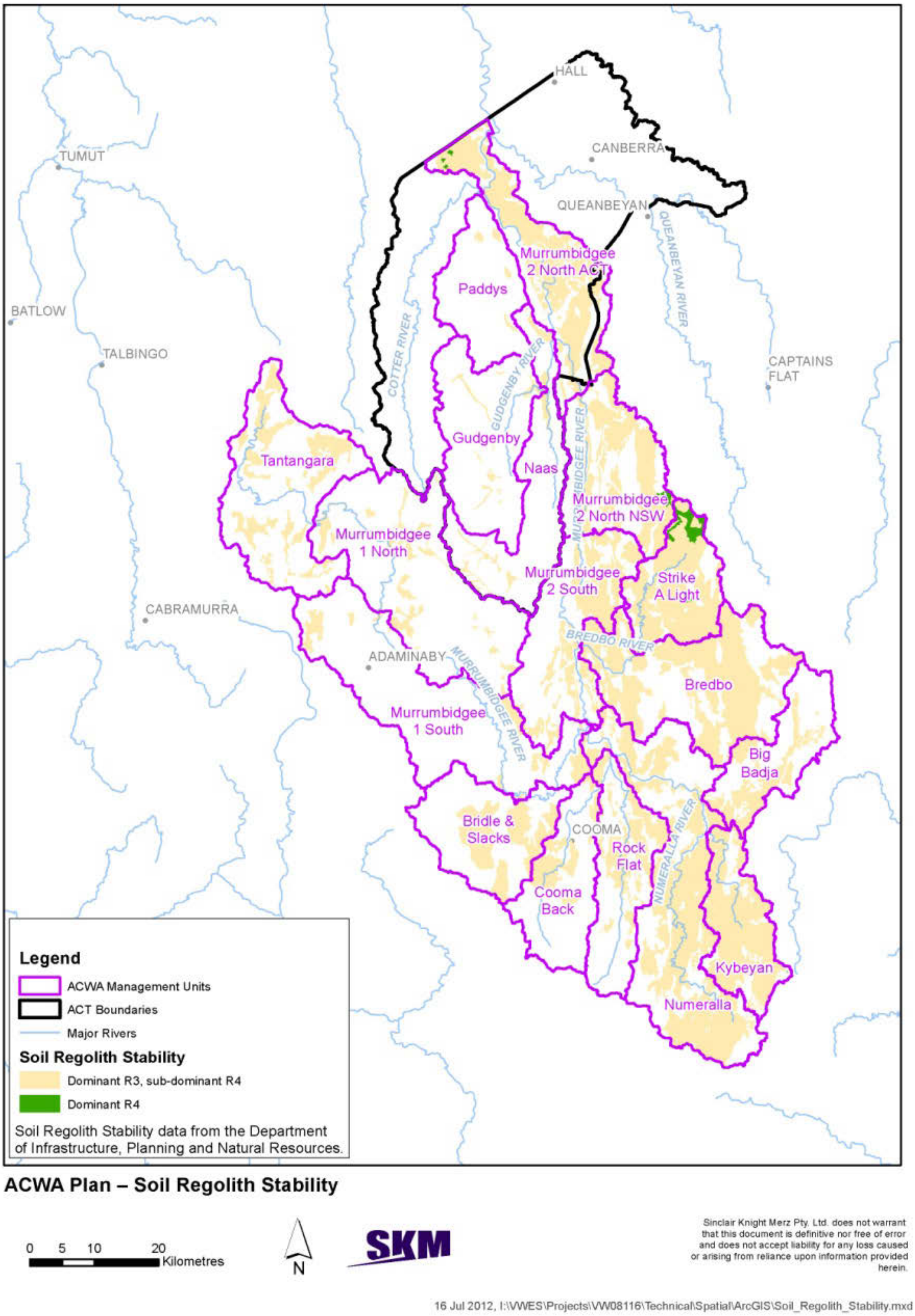

Figure 8 Soil Regolith Stability in the ACWA Plan area

A large proportion of the ACWA Plan area contains soils that have significant potential to release fine sediment and hence contribute to downstream turbidity. Land management activities throughout the ACWA Plan area should consider the limitations of these soil types in particular their dispersive characteristics.

2.2 Climate

The ACWA Plan area has a diverse climate ranging from alpine and sub-alpine areas in the south through to a milder continental climate in the north around Canberra. Rainfall varies across the plan area with mean annual rainfall exceeding 1600 mm/yr in the south-west of the Plan area through to less than 500 mm/yr in the south-east. Average annual rainfall for the ACWA Plan area is presented in Figure 2.

A large portion of the ACWA Plan area is located in a rain shadow and in many areas evapotranspiration is significant relative to precipitation (see Figure 9).

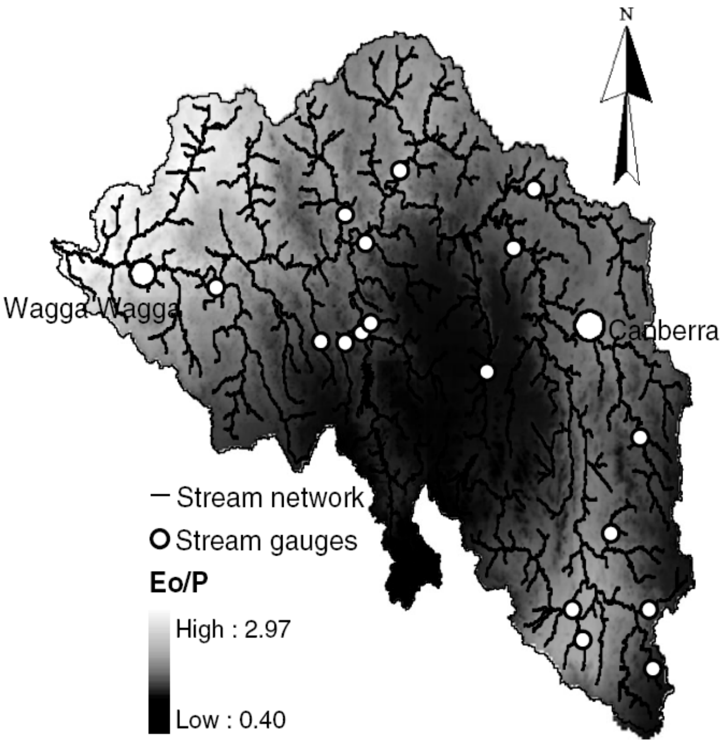

Figure 9 Evapotranspiration/precipitation relationship in the study area (Source:[45]). Darker areas indicate precipitation exceeding evapotranspiration, lighter areas evapotranspiration rates exceeding precipitation rates.

In some areas of the catchment (notably the south and east of ACWA Plan area) the combination of low rainfall, high evaporation, occurrence of frosts and low soil moisture results in a climate in which it is difficult to maintain adequate ground cover which can result in a variety of land management problems including soil erosion resulting in the generation of turbidity[46].

[45] Wilkinson SN., Young WJ., DeRose RC. (2006) Regionalizing mean annual flow and daily flow variability for basin-scale sediment and nutrient modelling, Hydrological Processes, 20, 2769–2786
[46] Lua MJ, (1994) Soil Landscapes of the Cooma 1:100,000 map sheet

2.3 Landuse

A range of land uses are present within the ACWA Plan area. Dryland grazing and cropping are the dominant land uses throughout the ACWA Plan area. Forestry (both native hardwood and plantation softwood) is present in many locations within the ACWA in both NSW and the ACT. Small patches of irrigated agriculture are present adjacent to the major waterways of the plan area particularly the Murrumbidgee River. Several large areas set aside for nature conservation are located in the plan area including parts of the Kosciuszko National Park, Wadbilliga National Park and Namadgi National Park. Urban development has occurred around the major centres of Cooma, Adaminaby and Canberra.

2.4 Topography

The ACWA Plan area exhibits higher relief when compared to the rest of the Murrumbidgee Catchment. It is dominated by the Murrumbidgee corridor that lies between the high country of the Murrumbidgee Batholith (Clear Range) to the west and the Tinderry Range to the east (also granite bodies). The southern part of the Plan area is dominated by the flat Downs country of the Monaro Plain.

Parts of the ACWA Plan area with steeper topography (greater than 25% slope) or with shallow soil profiles (rocky areas) are typically more vulnerable to erosion[47] and hence turbidity generation.

2.5 Water quality

Monitoring of water quality in the plan area is undertaken by a range of parties in both NSW and the ACT. As part of the project literature review a high level assessment 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 observations about the data were made:

- 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

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[47] Central West Catchment Management Authority (2008) *Land and Soil Capability - How We Safely Manage the Land,* Wellington NSW

- 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.

2.6 Summary

Overall catchment condition varies across the geographic breadth of the ACWA Plan area. This variation is a consequence of a multitude of factors including those noted in the preceding sections. With regard to the generation of turbidity two key variables, soil type and climate, stand out as potentially making certain areas of the catchment more vulnerable to erosion and the generation of turbidity.

The prevalence of 'vulnerable' soils in parts of the Plan area predisposes these areas to erosion and the generation of turbidity under certain conditions. This, when combined with climatic limitations on the growth of groundcover vegetation (due to low rainfall, high evaporation, occurrence of frosts and low soil moisture), places large portions of the ACWA Plan area at significant risk of erosion and the generation of turbidity.

3 Conceptualisation erosion processes

3.1 History of landscape changes

The upper Murrumbidgee Catchment has undergone significant landscape changes since European Settlement. The nature of the historical changes that have taken place have been documented in a number of previous reports and these are summarised here.

Vegetated shallow valley floor depressions were common at the time of European Settlement. Many of the streams consisted of unincised 'swampy meadows' or a series of deep pools, commonly referred to as chain of ponds, linked by shallow vegetated channels and swampy 'flats' [48,49,50].

Land clearing and the introduction of sheep and cattle associated with settlement triggered stream incision and gully erosion. This gully and incised stream network are formed over the first few decades following clearing and many of the gully heads were believed to have stabilised relatively quickly[51].

Radionuclide and SedNet studies indicate that the majority of sediment load in the Murrumbidgee River is derived from gully and channel erosion[52,53,54]. Some of the tributary streams in the upper Murrumbidgee are being colonised by Typha and Phragmites[55]. These wetlands have the potential to trap sediments[56] and assist in controlling sediment, nutrient and water delivery to the channel[57].

The indications from the completion of desktop review and field assessments is that different catchment areas in the Upper Murrumbidgee vary in their erosion activity and stage of response to initial landuse change associated with early settlement. Ongoing landuse practices and changes in the magnitude and frequency of flood events can also have a disturbing influence on the recovery of these catchment areas.

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[48] Starr, B.J., Wasson, R.J. and Caitcheon, G. (1999) Soil erosion, phosphorus and dryland salinity in the Upper Murrumbidgee: past change and current findings. Upper Murrumbidgee Catchment Coordinating Committee 132 pp.

[49] Prosser, I.P., Chappell, J., Gillespie, R., 1994. Holocene valley aggradation and gully erosion in headwater catchments, southeastern highlands of Australia. Earth Surface Processes and Landforms 19, 465–480

[50] Eyles, R.J., 1977. Changes in drainage networks since 1820, Southern Tablelands, N.S.W. Australian Geographer 13, 377–387.

[51] Wallbrink, P. and Olley, J. (2004) Sources of fine grained sediment in incised and un-incised channels, Jugiong Creek, NSW, Australia. In Sediment Transfer through the Fluvial System (Proceedings of a symposium held in Moscow, August 2004) IAHS Publication No. 288.

[52] Olley, J.M. and Wasson, R.J. (2003) Changes in the flux of sediment in the Upper Murrumbidgee Catchment, South-eastern Australia, since European settlement. Hydrological Processes 17, 3307-3320.

[53] Wallbrink, P.J. (1996) Use of radionuclides in studies of erosion and sedimentation. Unpublished PhD Thesis, Australian National University.

[54] Wilkinson, S., Jansen, A., Watts, R., Read, A. and Miller, T. (2004) Techniques for targeting, protection and rehabilitation of riparian vegetation in the middle and upper Murrumbidgee catchment. CSIRO Land and Water Technical report No 37/04. October 2004.

[55] Olley, J. and Scott, A. (2002) Sediment supply and transport in the Murrumbidgee and Namoi Rivers since European settlement. CSIRO Land and Water, Canberra, Technical Report 9/02, December 2002.

[56] Zierholz, C., Prosser, I.P., Fogarty, P.J. and Rustomji, P. (2001). In stream wetlands and their significance for channel filling and the catchment sediment budget, Jugiong Creek., New South Wales. Geomorphology 38: 221-235.

[57] Olley, J. and Scott, A. (2002) Sediment supply and transport in the Murrumbidgee and Namoi Rivers since European settlement. CSIRO Land and Water, Canberra, Technical Report 9/02, December 2002.

3.2 Erosion processes

Sheet erosion, rill and gully erosion, tunnel erosion, bank erosion and bed erosion have all been identified as processes operating in the upper Murrumbidgee catchment. This section describes each of these erosion processes.

3.2.1 Sheet erosion

Sheet erosion occurs when surface material is detached by raindrops or water flow and transported by unconfined overland flow over the soil surface [58]. Sheet erosion is more likely to occur on bare areas, associated with cattle and sheep tracks, rather than areas where pasture is established. Areas where loose shallow topsoil overlies a dense subsoil are most susceptible to sheet erosion. The eroding and transporting power of sheet flow are functions of the depth and velocity of runoff for a given size, shape, density of soil particle or aggregate [59]. Soils with a high proportion of silt or fine sand lack cohesion and are more likely to be eroded by overland flow as they have a low cohesive strength. Dispersive soils are also more erodible, as aggregates break up when wet and the individual clay particles are easily entrained [60]. Broad-scale sheet erosion is not believed to be a major problem in the upper Murrumbidgee catchment. However, sheet erosion may be more expected to be an issue after a period of drought when distribution of ground covers is low and areas of bare soil are more widespread. Sheet erosion was noted as an issue in the headwaters of Buchan Creek (Site 3).

3.2.2 Rill and gully erosion

Rill, and gully erosion are types of water erosion in which runoff is conducted through channels[61]. Rills are narrow open channels less than 30 cm in depth, which often occur on agricultural land and can be obliterated by cultivation. The dimensions of these features tend to increase in response to successive runoff-producing storms and may eventually become gullies. A gully is an open channel which is often steep-sided, U or V-shaped in cross-section, bare of vegetation and of sufficient depth that it cannot be traversed by agricultural machinery[62].

Many of the gullies that are now apparent in southeast Australia eroded in the period between 1850 and 1950 when the disturbance of valley floor vegetation and the introduction of hoofed stock increased runoff and decreased erosion resistance[63]. When runoff is concentrated in hill slope hollows, the erosivity of flow increases, sometimes incising gullies into the valley floor. Once initiated, gullies spread at an exponentially declining rate with much of the networks being formed within the first few decades[64].

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[58] Rose, C.W., 1993. Soil erosion by water. In G.H. McTainsh and W.C. Boughton (eds.), Land Degradation Processes in Australia. Longman Cheshire, Melbourne: 149-87

[59] Schwab, G., R.K. Frevert, T.W. Edminster and K.K. Barnes, 1981. Soil and water conservation engineering. John Wiley & Sons.

[60] Young, A. and R. Young (eds.), 2001. Soils in the Australian Landscape. Oxford University Press, Melbourne.

[61] Rose, C.W., 1993. Soil erosion by water. In G.H. McTainsh and W.C. Boughton (eds.), Land Degradation Processes in Australia. Longman Cheshire, Melbourne: 149-87.

[62] Fitzpatrick, R.W., S.C. Boucher, R. Naidu and E. Fritsch, 1994. Environmental consequences of soil sodicity. Australian Journal of Soil Research, 32: 1069-93.

[63] Prosser, I.P. and C.J. Slade, 1994. Gully formation and the role of valley-floor vegetation, southeastern Australia. Geology, 22: 1127-30.

[64] Graf, W.L., 1977. The rate law in fluvial geomorphology. American Journal of Science, 277: 178-91.

Channel initiation by overland flow has been viewed as a threshold phenomenon related to the size of the contributing area and its slope[65]. The relationships between source area and slope have been explored in a number of environments to predict the onset and the stable extent of gully networks (e.g.[66,67,68]). Once incision occurs, gully heads typically migrate upslope until some threshold of contributing area and/or slope is met. At this point runoff – capable of further incision - cannot be generated and the gully stabilises in its headward extent. Vegetation and the erodibility of the underling soil also influence topographic thresholds. The loss of groundcover and enhanced runoff results in an increase in the erosiveness of flows on the valley floor. The effect of this is to reduce the critical area/slope required for gully initiation and stabilisation.

The other dimensions of gully networks are gully width and depth. Gullies often continue to incise down to bedrock or until some stable gradient is achieved from the baselevel of the downstream drainage network (see[69]). After the gully floor has stabilised the gully walls tend to lay back under the influence of water and gravity until they are reduced to relatively stable slopes[70]. As gully floor elevation and sidewall slopes stabilise, vegetation is able to colonise the surfaces, further dampening the effects of any erosion processes.

Relating gully morphology to erosion process provides a useful field technique to assess gully stability. The further a gully head from a drainage divide, the more potential there is for continued headward extension. Secondary nickpoints in gully floors indicate that some change in base-level has renewed the incision process and that the gullies will continue to deepen. Deepening gullies will promote sidewall instability and maintain the walls at steep angles. Lower angles on the sidewalls indicate general gully stability. Overtime, with the establishment of vegetation, the gully will begin to infill and begin the process of landscape recovery.

Much of the gully erosion in South East Australia occurred only after valley floor vegetation had been disturbed[71]. However, other factors, such as the strength and hydraulic properties of valley-floor soils, also influence erosion processes. Many Australian soils have hard-setting A-horizons, and more clayey sodic B-horizons[72]. The B-horizon often has a lower permeability and water is forced laterally and moves as throughflow downslope. If the clays in the B-horizon are dispersive, fine soil particles can be carried in suspension in the throughflow. The transport of clay-sized particles by subsurface water leads to piping, tunnelling and seepage erosion[73]. The resultant removal of sediments from an erosional pipe may contribute to further headward extension of the gully network. Hence, while the

[65] Horton, R.E., 1945. Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. Geological Society of America Bulletin, 56: 275-370.

[66] Dietrich, W.E., C.J. Wilson, D.R. Montgomery, J. McKean and R. Bauer, 1992. Erosion thresholds and landsurface morphology. Geology, 20: 675-9.

[67] Prosser, I.P. and B. Abernethy, 1996. Predicting the topographic limits to a gully network using a digital terrain model and process thresholds. Water Resources Research, 32(7): 2289-98.

[68] Morgan, R.P.C. and D. Mngomezulu, 2003. Threshold conditions for initiation of valley-side gullies in the Middle Veld of Swaziland. Catena, 50: 401-14.

[69] Schumm, S.A., M.D. Harvey and C.C. Watson, 1984. Incised Channels: Morphology, Dynamics and Control. Water Resources Publications, Littleton, Colorado.

[70] Crouch, R.J., 1987. The relationship of gully sidewall shape to sediment production. Australian Journal of Soil Research, 25: 531-9.

[71] Prosser, I.P. and C.J. Slade, 1994. Gully formation and the role of valley-floor vegetation, southeastern Australia. Geology, 22: 1127-30.

[72] Young, A. and R. Young (eds.), 2001. Soils in the Australian Landscape. Oxford University Press, Melbourne

removal of vegetation has increased runoff rates, the characteristics of the underlying soils can have a strong influence on the potential for gullying to occur.

3.2.3 Tunnel erosion

Piping or tunnel erosion is a process involving the hydraulic removal of subsurface soil, causing the formation of underground tunnels in landscapes[74]. Tunnel erosion is a complex land management problem owing to difficulties in locating the site(s) of tunnel initiation, the variety of initiation mechanisms, and the often nonsaline-sodic and highly erodible nature of the B horizon clays in which these channels frequently form[75]. The environmental consequences of tunnelling are similar to those produced by gullying. These include injury to livestock and damage to farm equipment when the surface soil gives way, as well as reduced trafficability resulting from paddock dissection and diminished amenity of the affected land.

The mechanisms causing tunnel initiation have been studied by a number of researchers in northeastern Victoria[76,77,78,79]. Sheet erosion is often cited as a precursor to the onset of tunnelling. The bare patches of ground which remain are subjected to the mechanical action of rainsplash which gives a crusted appearance to the often poorly structured A-horizon, reducing its permeability and producing increased surface runoff[80]. Sparse ground cover also increases the erosional power of surface and subsurface runoff. Seasonal desiccation of the surface, slaking, the development of tension cracks and disturbance by hooved stock breaks up the structure of the hardsetting soils, and provides points of higher infiltration and initiation points for tunnels to form. Tunnel initiation may occur when surface runoff collects in depressions created by the removal of a tree stump, and flows along the path of an old root line[81].

Tunnels may be initiated through concentrated flow in hollows. Accelerated weathering and destruction of the soil structure by persistent saturation increases surface and subsurface height differentials between seepage zones and ridges and enlarges the soil-water catchment area and leads to a greater capture of surface runoff. This results in headwater sapping and downslope erosion by inertia as a more efficient drainage network develops. Where cracks or voids in the soils (i.e. old root lines) are present, concentrated flow and similar extension and enlargement may occur

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[73] Young, A. and R. Young (eds.), 2001. Soils in the Australian Landscape. Oxford University Press, Melbourne

[74] Boucher, S.C., 2003b. Tunnel erosion. Department of Sustainability and Environment. On line: www.dpi.vic.gov.au/web/root/Domino/vro/vrosite.nsf/pages/lwm_land_deg_tunnel

[75] Boucher, S.C., 2003b. Tunnel erosion. Department of Sustainability and Environment. On line: www.dpi.vic.gov.au/web/root/Domino/vro/vrosite.nsf/pages/lwm_land_deg_tunnel

[76] Downes, R.G., 1946. Tunnelling erosion in north-eastern Victoria. Journal of the Council for Scientific and Industrial Research, 19: 283-92.

[77] Downes, R.G., 1949. A soil, land-use, and erosion survey of parts of the Counties of Moira and Delatite, Victoria. CSIRO Australia, Bulletin No. 243.

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[79] Boucher, S.C. and J.M. Powell, 1994. Gullying and tunnel erosion in Victoria. Australian Geographical Studies, 32: 17-26.

[80] Boucher, S.C., 1990. Field Tunnel Erosion: its Characteristics and Amelioration. Monash University, Clayton and Department of Conservation and Environment, East Melbourne.

[81] Boucher, S.C., 2003b. Tunnel erosion. Department of Sustainability and Environment. On line: www.dpi.vic.gov.au/web/root/Domino/vro/vrosite.nsf/pages/lwm_land_deg_tunnel

initiating tunnels[82]. High hydraulic gradients, the presence of soluble ions, prolonged periods of drought producing desiccation cracks, and irregular heavy storms activate the tunnels[83].

Gully formation by the merging of collapsed tunnels is typically the ultimate outcome of tunnel erosion[84,85]. Tunnel initiation and development may also commence as a result of gully erosion linked to the increased gradient and potential for throughflow that results from incision of a gully head or expansion of gully sidewalls. This may occur through one of two mechanisms. Precipitation and surface runoff may enter the surface soil near the bank, and move into the gully through cracks which provide an exit for concentrated throughflow. The steeper hydraulic gradient enables dispersive clays to be removed and a tunnel forms. The second mechanism is that of hill slope seepage concentrating in a relatively permeable layer in the gully wall, facilitating headward tunnel extension.

3.2.4 Bank erosion

The processes that lead to streambank erosion can vary markedly within a catchment. The nature of the processes responsible depend on a number of factors including in-stream flows, sediment transport, vegetation characteristics and the geotechnical properties of the bank[86]. In general terms, there are three main groups of processes by which bank erosion occurs: sub-aerial preparation; fluvial entrainment; and mass-failure mechanisms. Studies have shown that these processes are also likely to be more dominant than others depending on the position of the eroding bank section within the catchment[87]. In small river catchments, subaerial preparation mechanisms have been shown to dominate the erosion processes (windthrow of stream-side trees, damming of LWD, desiccation, rainsplash and micro-rill development). Fluvial entrainment processes (scour and entrainment of sediments) are generally dominant in middle order basins, and mass-failure mechanisms (bank erosion through failure of bank materials) are more a feature of larger catchments. The removal of vegetation from channel banks has the effect of decreasing the resistance of the materials to erosion. Clearing of riparian vegetation is likely to have been a major factor that has contributed to past and present problems of bank erosion in the catchment.

3.2.5 Bed erosion

Bed erosion occurs in response to an excess of flow energy, shear stress or stream power (sediment transporting capacity) relative to the amount of sediment supplied to the channel. Where bed erosion occurs and it is limited in magnitude as well as in a spatial and temporal context, it is often referred to as scour. Scour can occur over periods of hours to days and affects localised areas in

[82] Bull, L.J. and M.J. Kirkby, 2002. Channel heads and channel extension. In L.J. Bull and M.J. Kirkby (eds.), Dryland rivers: hydrology and geomorphology of semi-arid channels. John Wiley & Sons, Ltd., New York: 263-8.

[83] Bull, L.J. and M.J. Kirkby, 2002. Channel heads and channel extension. In L.J. Bull and M.J. Kirkby (eds.), Dryland rivers: hydrology and geomorphology of semi-arid channels. John Wiley & Sons, Ltd., New York: 263-8.

[84] Young, A. and R. Young (eds.), 2001. Soils in the Australian Landscape. Oxford University Press, Melbourne.

[85] Boucher, S.C., 2003b. Tunnel erosion. Department of Sustainability and Environment. On line: www.dpi.vic.gov.au/web/root/Domino/vro/vrosite.nsf/pages/lwm_land_deg_tunnel

[86] Abernethy, B. and I.D. Rutherfurd, 1998. Where along a river's length will vegetation most effectively stabilise stream banks? Geomorphology, 23(1): 55-75.

[87] Lawler, D.M., 1995. The impact of scale on the processes of channel-side sediment supply: a conceptual model. In Effects of Scale on Interpretation and Management of Sediment and Water Quality (Proceedings of a Boulder Symposium), Boulder. IAHS Publication No. 226: 175-84.

response to flow associated with discrete storm events. In contrast, when a section of channel experiences an excess of flow energy for an extended period of time resulting in continued bed erosion, this is referred to as degradation. Degradation represents a systematic lowering of the channel over a period of years and can affect long sections of a river or entire drainage networks[88].

Degradation is initially rapid and then slows as the channel progresses through a sequence of adjustments that return the degraded section to a new equilibrium. As the bed degrades, heightened sediment loads, channel gradients and a number of other variables decrease non-linearly with time. Bank heights also increase and upon reaching a critical height and angle these banks fail and the channel begins to widen. Channel widening is the most efficient way that a channel can reduce is excessive flow energy as it leads to direct reduction in unit stream power. As the channel widens and flow energy is reduced, riparian vegetation begins to stabilise sediments at the channel margins. The sequence of channel changes serves to counteract the effects of the initial disturbance and restore stability to the incised channel[89].

3.3 Conceptual model of erosion processes

The gullies, tributaries and river channels of the upper Murrumbidgee catchment have in response to historical land use change undergone a process of degradation that follows a generalised sequence of channel changes. This sequence of channel changes is consistent with that which has been documented in many different parts of Australia and overseas, where streams have been forced to lower their beds as a result of changes in land use or other disturbing influences (i.e. channelisation, floods).

This sequence of channel changes have been conceptualised by Schumm et al. (1984)[90] to illustrate an idealised downstream sequence of channel forms associated with the instability that results from base level lowering (see Figure 10). Using time for space substitution, the same sequence of stages may be expected to occur through time at any given location as an erosional nickpoint or oversteepened zone migrates upstream. These models can be used to predict the stage of adjustment that the channel has reached and its future trajectory[91].

[88] Simon, A. and S. Darby, 1999. The nature and significance of incised river channels. In S.E. Darby and A. Simon (eds.), Incised river channels: processes, forms, engineering and management. John Wiley & Sons Ltd., New York: 3-18.

[89] Simon, A. and S. Darby, 1999. The nature and significance of incised river channels. In S.E. Darby and A. Simon (eds.), Incised river channels: processes, forms, engineering and management. John Wiley & Sons Ltd., New York: 3-18.

[90] Schumm, S.A., M.D. Harvey and C.C. Watson, 1984. Incised Channels: Morphology, Dynamics and Control. Water Resources Publications, Littleton, Colorado.

[91] Wallerstein, N.P. and C.R. Thorne, 2003. Influence of large woody debris on morphological evolution of incised, sand-bed channels. Geomorphology, 57: 1-21

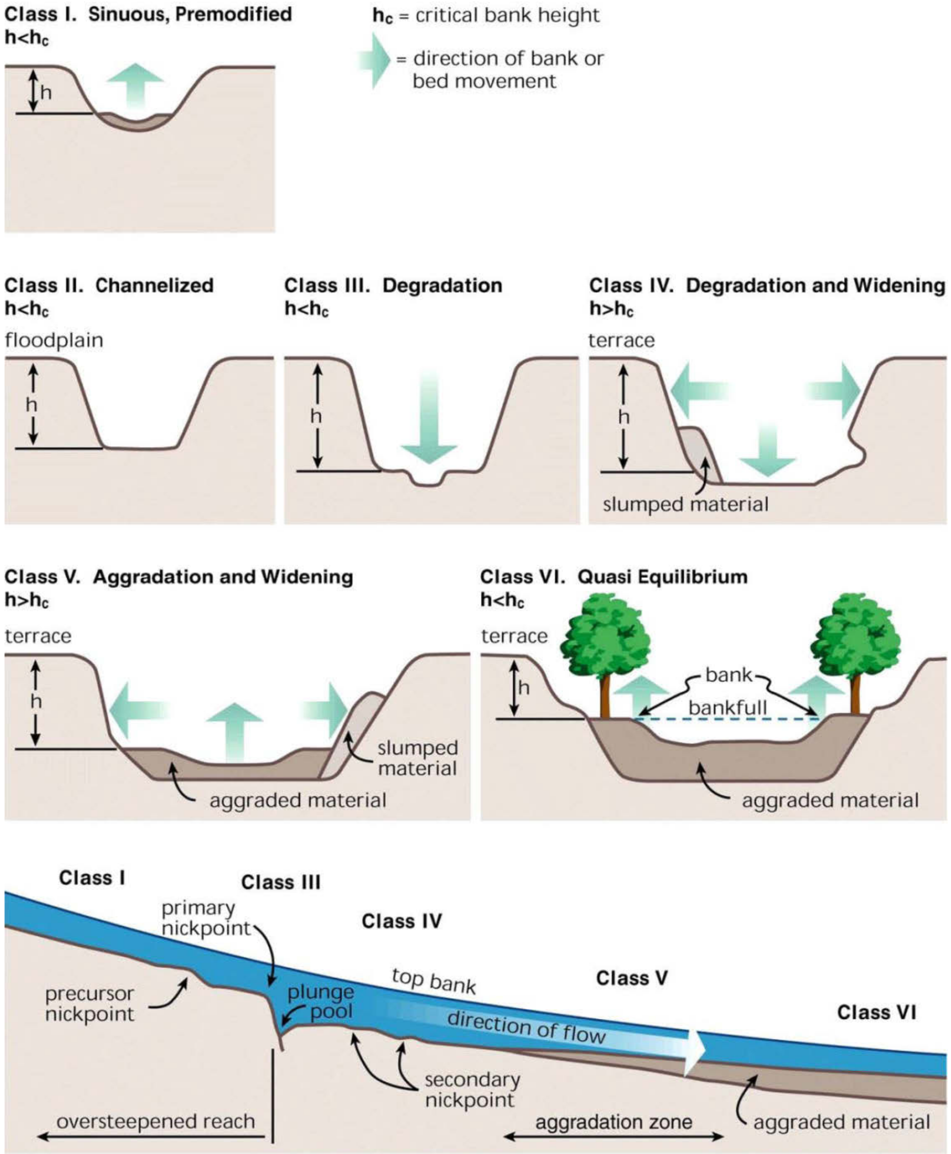


Figure 10 Longitudinal profile of incised channel showing idealised stages of channel evolution (after Schumm, Harvey et al. 1984[92]).

Following an incisional stage (Class III), the channel will begin to widen through bank erosion and failure (Class IV). Channel widening will continue but then begin to slow as flow energy is reduced and the channel begins to aggrade its bed (Class V). Vegetation then commences to establish at the channel margins and across the bed assisting in the final recovery of the stable channel (Class VI).

The description of channel processes discussed above and conceptual model outlined can be used in the Upper Murrumbidgee Catchment to:

- assist in explaining erosion issues currently faced at different sites;
- identify the trajectory of erosion processes and the implications this may have in contributing fine sediments; and
- aid in the development of appropriate remediation measures.

[92] Schumm, S.A., M.D. Harvey and C.C. Watson, 1984. Incised Channels: Morphology, Dynamics and Control. Water Resources Publications, Littleton, Colorado.

Examples of channels at different stages of channel evolution are presented below.

Gully of Buchan Creek
Degradation (Class III)

Buchan Creek
Degradation and Widening (Class IV)

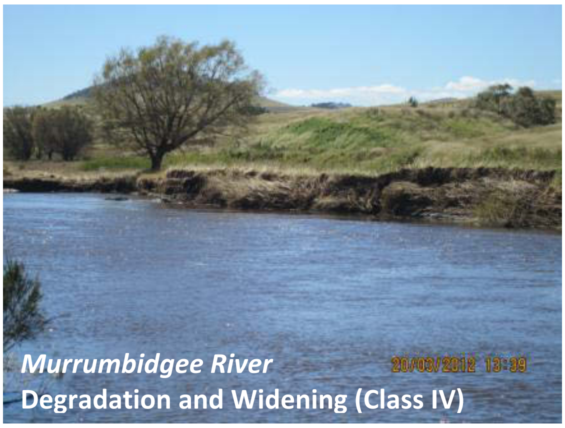
Tributary of Naas
Aggradation and Widening (Class V)

Tributary of Kybeyan River
Quasi Equilibrium (Class VI)

The conceptual model is used to identify what class of channel the different sites/sub-catchments are at and then provide advice on what remediation measures are appropriate for mitigating the erosion processes operating in each class.

For example, if you have a Class III or IV incising channel, than you need to focus on stabilising the bed to prevent further incision. If the channel is no longer incising, and is in Class V (aggradation and widening) than you can switch your focus to measures that target mitigating erosion of the channel banks and channel widening (revegetation, rock beaching, pile fields etc).

It is important to note that the occurrence of floods can have a destabilising influence on channel stability. Bank erosion and widening is a typical response to floods. A Class VI Quasi Equilibrium channel can be transformed to a Class IV (degradation and widening) or Class V (aggradation and widening) state in response to floods. Examples of this are provided in photographs below.



Murrumbidgee River
Degradation and Widening (Class IV)

Gudgenby River
Aggradation and Widening (Class V)

3.4 Process for prioritisation of new sites

The following prioritisation process would be applied if assessing a specific issue within the Upper Murrumbidgee catchment.

Step 1 Assess site

Step 2 Value =1

Step 3 Threat = 1

Step 4 Likelihood = obtained from section 4.5 for specific catchment

Step 5 Consequence = apply one rating only from section 4.4 dependent on issue (e.g. bank erosion or bed deepening)

Step 6 Determine trajectory of erosion processes

Step 7 Determine risk score by multiplying ***Value x Threat x Consequence x Likelihood x Trajectory***

Step 8 Apply risk rating based on score from Table in section 12.3

4 Method

4.1 DSPIR approach

The broad approach that has been used for the ACWA Plan is the Driver- State-Pressure-Impact-Response (DSPIR) framework (**Error! Reference source not found.**). The use of this approach was requested as it aligns with the approach used to prepare the current Murrumbidgee CAP[93].

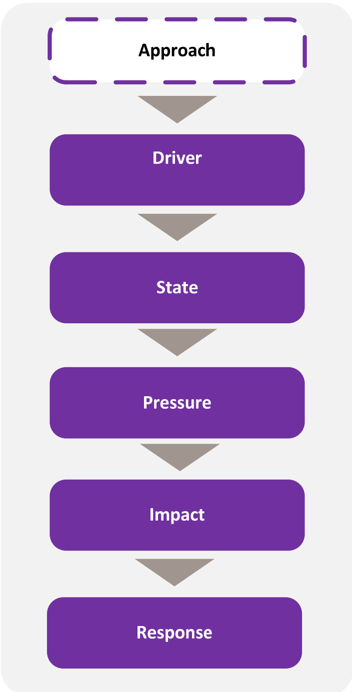


Figure 11: DSPIR Framework

The **Driver** for this Plan revolves around the need to consider turbidity generation in the Upper Murrumbidgee and the systemic issues emerging from drought conditions and recent floods within the catchment. These issues were specifically identified through a preliminary stakeholder workshop held among a range of interested community members, community groups and Government Agencies and a Literature Review.

The **State, Pressure** and **Impact** elements of the framework were considered through the process for prioritisation of sites for management intervention. Existing information was collated via the initial steps in the prioritisation method. This was then supplemented by new information gathered during the aerial assessments and finally the field based assessments.

The **Response** element of the framework is the proposed list of priority sites for Management Intervention (Chapter 7).

[93] ACWA Plan project brief (2011)

4.2 Prioritisation method

The methodology used to prioritised sites for management intervention is presented in Figure 12.

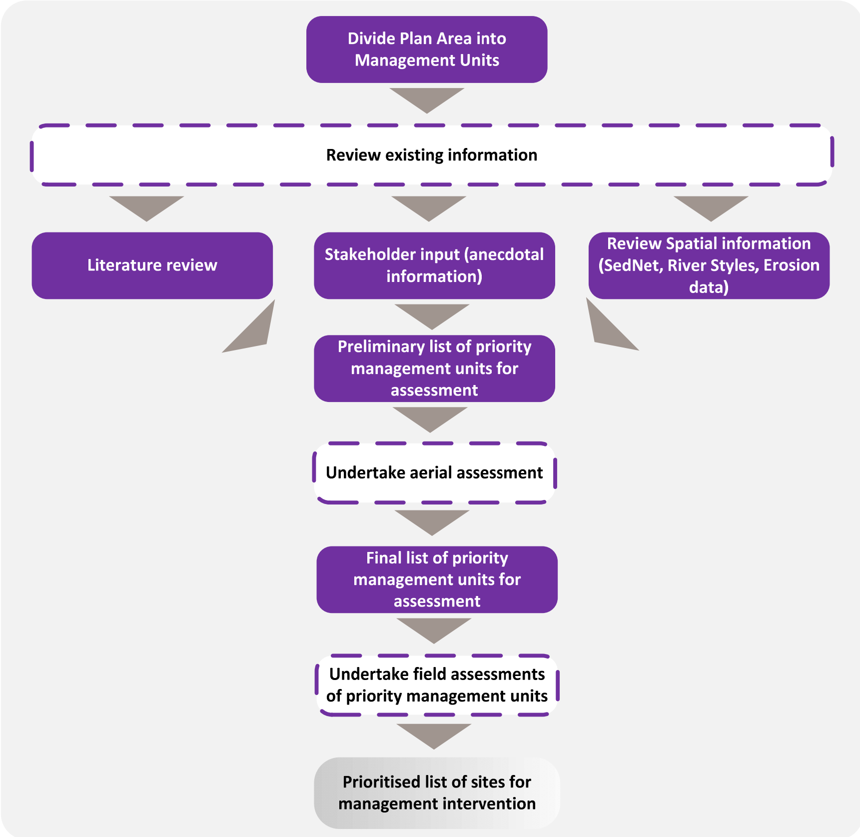


Figure 12 Process for prioritisation of sub-catchments

4.2.1 Step 1 Division of ACWA Plan area into Management Units

In order to manage issues of scale the ACWA Plan area (6,400 km^2) was divided into 17 management units (refer to Figure 13). These management units are broadly based upon those used in the sub-catchments defined by the Murrumbidgee CMA for the plan area. These have then been further divided to allow for a ready comparison of different parts of the plan area to be undertaken. Each management unit typically has similar geomorphic characteristics and is based around a single watershed.

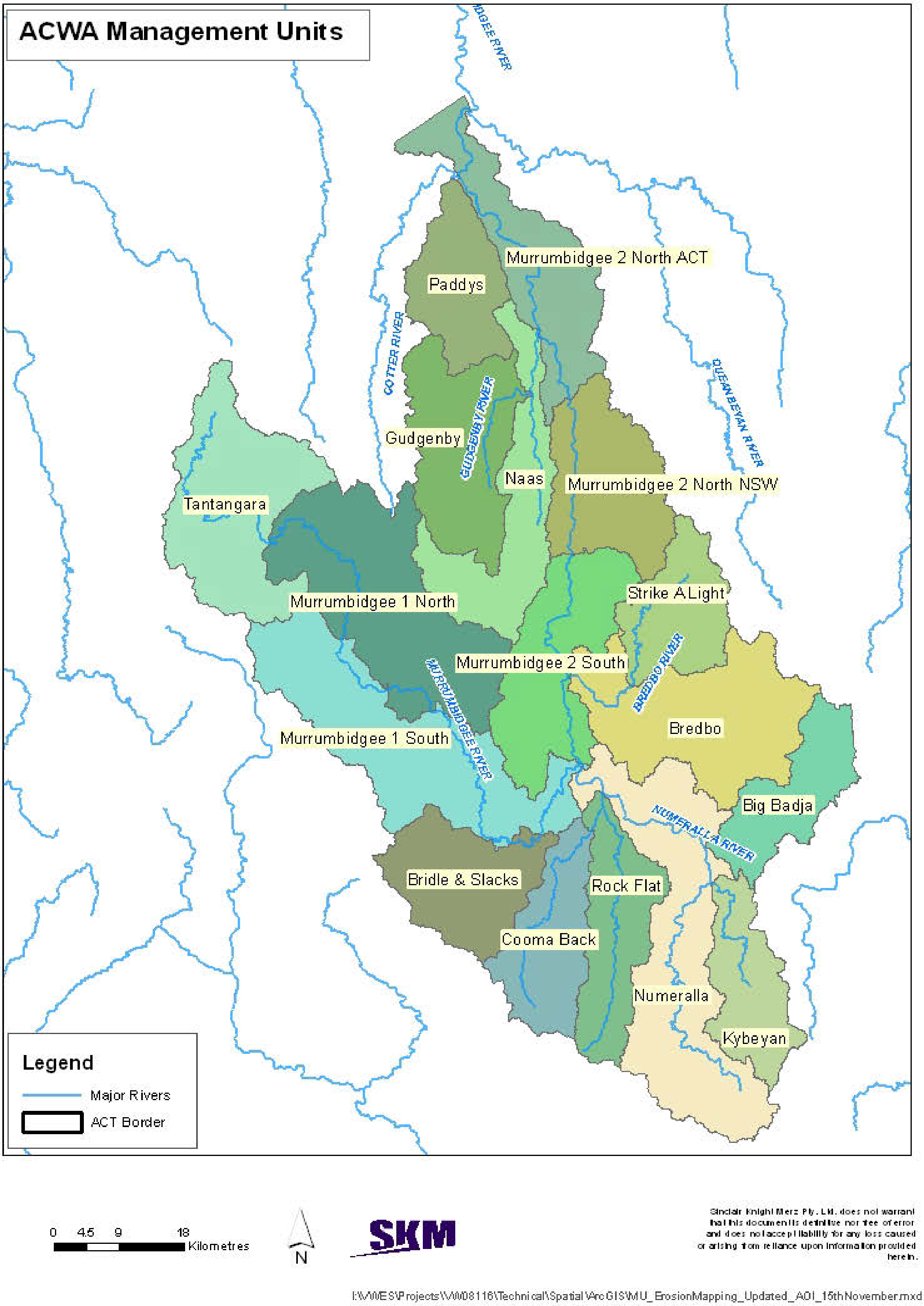


Figure 13 ACWA Plan management units

4.2.2 Step 2 Review of Existing Information

The second step in the Prioritisation Methodology was a review of existing information. Three types of information were reviewed:

1) Anecdotal (Stakeholder Provided) Information.
2) Review of Relevant Literature.
3) Review of Relevant Spatial Data Sets:
   - Spatial Data Analysis; and
   - Consideration of other spatial data.

These information sources were reviewed with the outcomes of this review presented in the ACWA Prioritisation Report. This report provided a preliminary list of Priority Management Units (and sites) for further Assessment.

4.2.2.1 Anecdotal (Stakeholder Provided) Information

A workshop with project stakeholders (the ACWA Advisory Group) was held in June 2011 with all Advisory Group members invited to attend and contribute information relating to the current condition of the catchment. Workshop attendees prepared marked up maps of the ACWA Plan area noting sites, reaches or sub-catchments where turbidity generation was occurring.

This information was utilised in the preparation of the Preliminary List of Priority Management Units for Assessment.

Key themes highlighted at the stakeholder workshop included:

- Potential impact on turbidity levels made by unsealed roads;
- Potential impact on turbidity as a result of sand and gravel extraction activities; and
- Potential impact on turbidity levels as a result of poor rural land management practices.

In addition to these key themes, a number of locations (sites, river reaches and sub catchments) were identified as potentially being sources of turbidity in the ACWA Plan area.

4.2.2.2 Review of Relevant Literature

A Literature Review was completed of documentation relevant to waterway and water quality management in the catchment of the Upper Murrumbidgee River. A summary of this literature review is presented in Appendix A.

The documents reviewed were all prepared in the period subsequent to 1993 and cover a range of geographic areas including the whole of the Murrumbidgee River catchment, the entirety of the ACT, just the Murrumbidgee River itself and other specific sub-catchments.

Key themes highlighted through the review included:

- Turbidity generation in the ACWA Plan area is being caused by a variety of erosion processes;
- Different parts of the ACWA Plan area are susceptible to different types of erosion (turbidity generation) processes;
- Erosion within many parts of the Plan area has occurred in a series of distinct phases with the most contemporary phase of significant erosion ending in the mid 20th century;
- Results of water quality monitoring have shown a trend towards increased turbidity levels in the Murrumbidgee River over time; and
- None of the documents reviewed consider the impacts of the 'millennium drought' on vegetation levels and the reaction of the catchment to rainfall events with reduced levels of groundcover vegetation.

In addition to these key themes, a number of locations (sites, river reaches and sub catchments) were identified as potentially being sources of turbidity in the ACWA Plan area. This information was utilised in the preparation of the Preliminary List of Priority Management Units for Assessment.

4.2.2.3 Spatial Data Analysis

A review and analysis was undertaken of relevant spatial datasets to identify potential locations of turbidity generation within the ACWA Plan area. The process used to complete the Spatial Data Analysis is presented in Appendix A. Three datasets were utilised:

1) SedNet Model Data (2004);
2) NSW Erosion Data (2003); and
3) Murrumbidgee River Styles Data (2011).

The scale that was used for the Spatial Data Analysis corresponded to the SedNet Model nodes. The nodes are River Reaches and represent the greatest level of detail at which the data was able to be interrogated.

The three datasets used for the spatial data analysis each had different characteristics that needed to be considered when combining them to undertake the analysis. These related to the age of the data, reliability of the data and the coverage of the data. Further detail relating to these attributes is contained in Table 11.

Table 11 Spatial data attributes

Dataset	Data Age	Data Type	Data Coverage
SedNet Model Data	2004	Modelled Data	Whole of Plan Area
NSW Erosion Data	Pre- 2003	Field Verified Data	NSW portion of Plan Area
Murrumbidgee River Styles Data	2011	Modelled & partially Field Verified	Whole of Plan area

Given the differing attributes of the three datasets the Spatial Data Analysis placed greater emphasis on the River Styles Data than the two other datasets. This was because the River Styles data had been collected more recently than the other data sets and the River Styles data considers any uncertainty in the data via the incorporation of a value for data confidence.

The output of the Spatial Data Analysis is represented in Figure 14. This figure notes the relative risk of erosion occurring in a particular River Reach (SedNet Model node) based on the three spatial data sets used. This analysis could be updated by the inclusion of new or updated datasets.

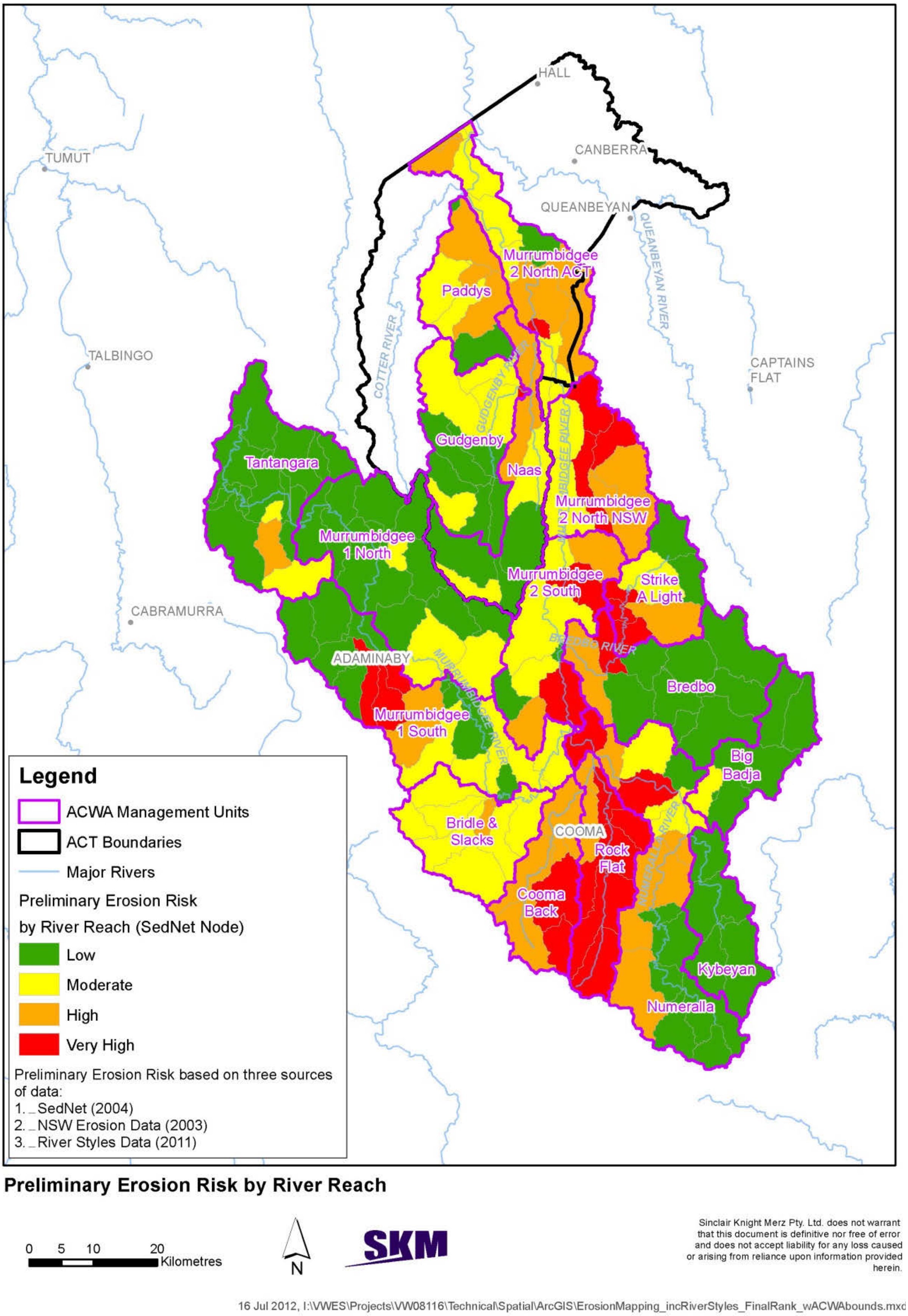


Figure 14 Erosion risk by river reach

The Spatial Data Analysis contributed to the prioritisation of Management Units for further assessment. In order to do this the relative erosion risk for each River Reach was collated up to the Management Unit Scale. Further detail on this process is contained in Appendix A- Prioritisation Report. This is represented in Figure 15.

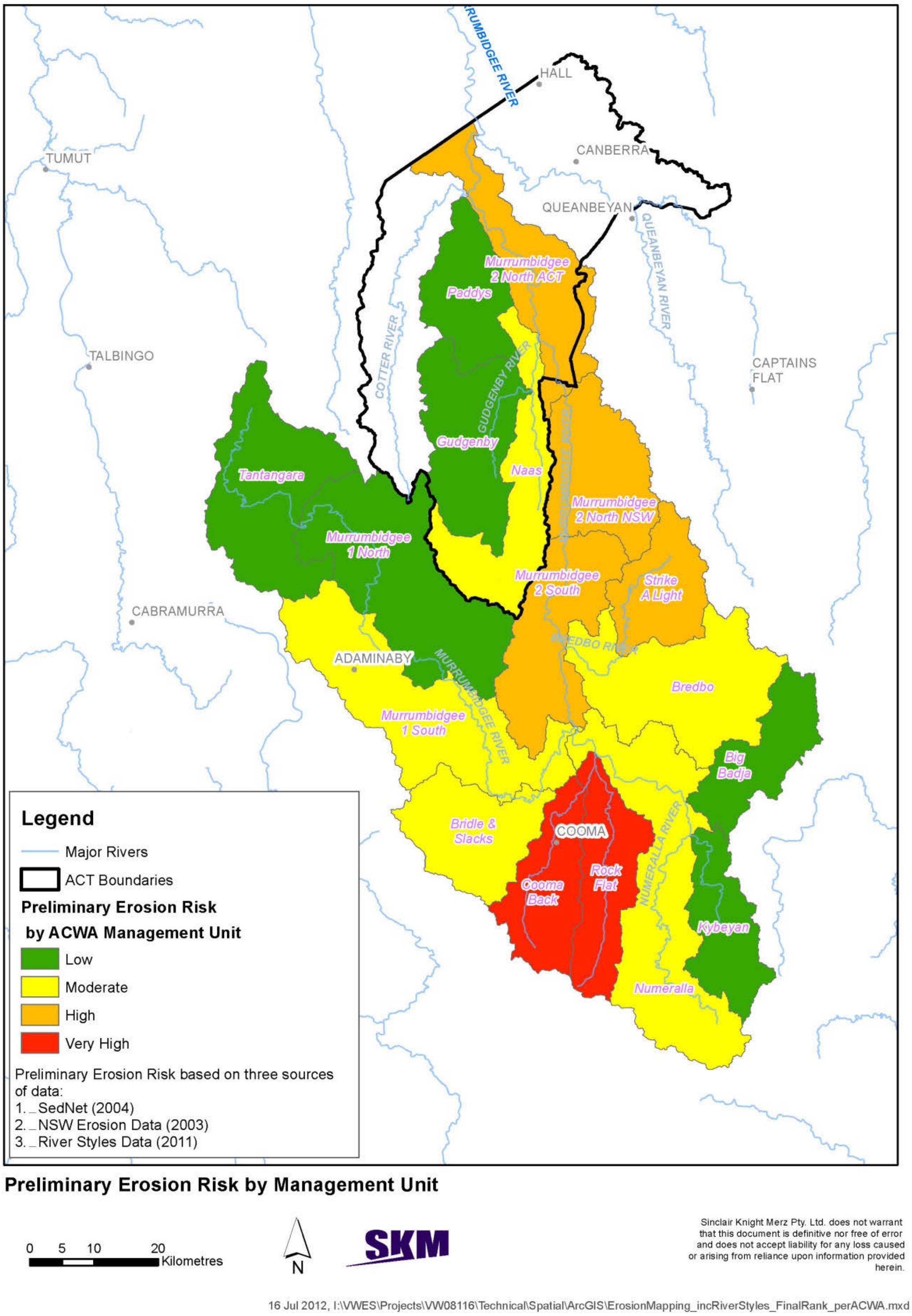


Figure 15 Erosion risk by management unit

4.2.2.4 Consideration of Other Spatial Data

The final element of the review of existing information was the consideration of other relevant spatial data. Two additional datasets were considered. These were:

- Locations of active bed erosion as noted within the River Styles data. A total of 9 sites were identified in the River Styles data where active bed erosion was occurring;
- Distribution of soils within the Plan Area that are noted as having low soil stability and high sediment movement potential. Soils of this type have a high potential to release sediment (generate turbidity) and the sediment released is typically fine and able to move significant distances.

4.2.2.5 ACWA Prioritisation Report

All of the information collected in Step 2 of the Methodology (Review of Existing Information) was presented in the ACWA Prioritisation Report as a preliminary list of management units requiring further assessment.

4.2.3 Step 3 Aerial Assessment of Plan Area

Following minor flooding in the ACWA Plan area in March 2012 an aerial assessment of the Plan Area was conducted to confirm the outcomes of Step 2 of the Methodology (Review of Existing Information). At the time that the aerial assessments were completed it was possible to clearly identify locations of erosion and the movement of fine sediment through the catchment.

4.2.4 Step 4 Final List of Priority Management Units for Assessment

As a result of the aerial assessments a revision was made to the relative Erosion Risk for each Management Unit. This is presented in Figure 16.

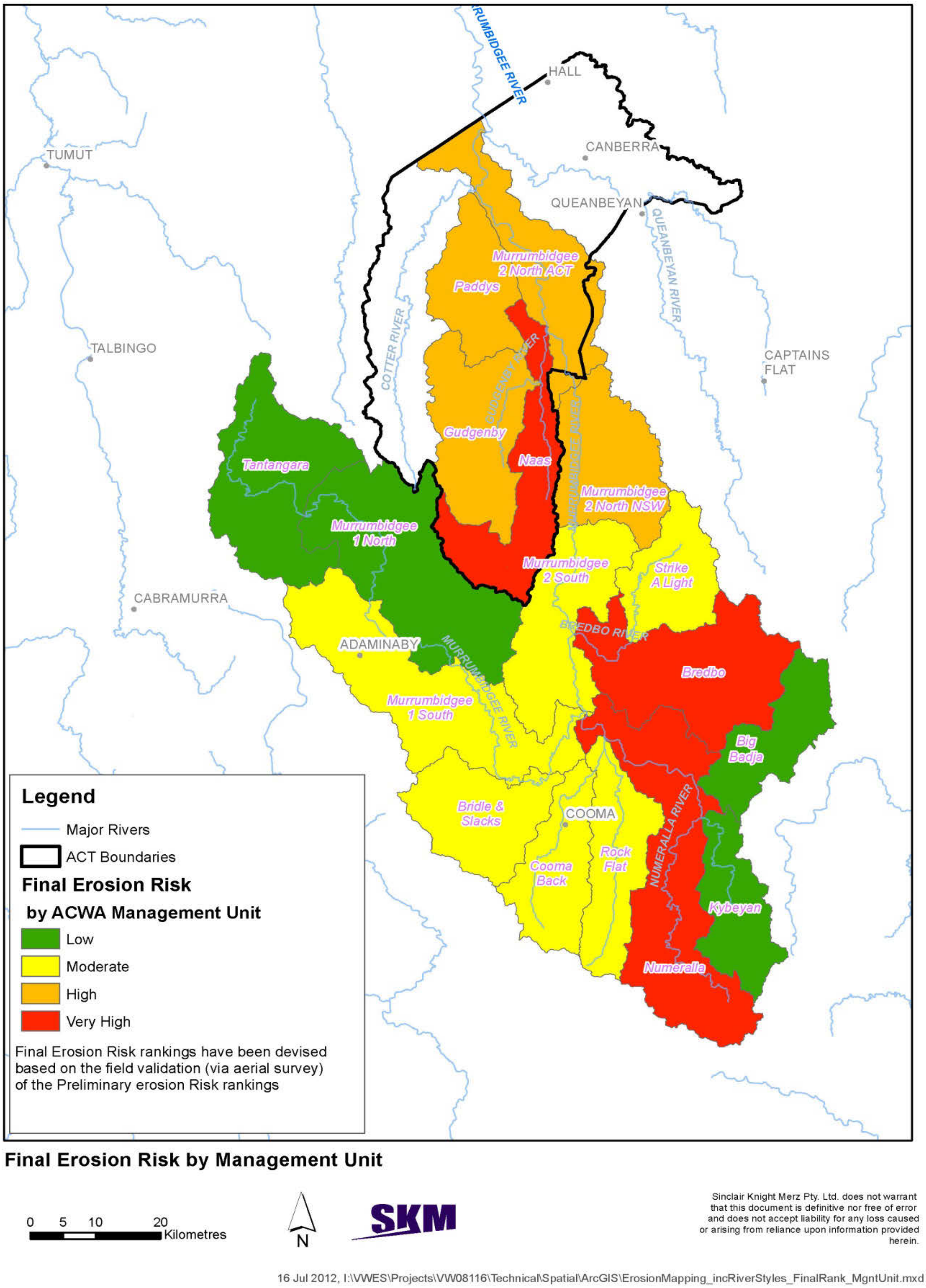


Figure 16 Final erosion risk by management unit

Table 12 notes the changes in relative Erosion Risk for each Management Unit based on the observations noted during the aerial assessments.

Table 12 Relative Erosion Risk for each management unit

Management Unit	Preliminary Erosion Risk Rank (Step 2)	Final Erosion Risk Rank (Step 4)
Big Badja	Low	Low
Bredbo	Moderate	Very High
Bridle & Slacks	Moderate	Moderate
Cooma Back	Very High	Moderate
Gudgenby	Low	High
Kybeyan	Low	Low
Murrumbidgee 1 North	Low	Low
Murrumbidgee 1 South	Moderate	Moderate
Murrumbidgee 2 North ACT	High	High
Murrumbidgee 2 North NSW	High	High
Murrumbidgee 2 South	High	Moderate
Naas	Moderate	Very High
Numeralla	Moderate	Very High
Paddys	Low	High
Rock Flat	Very High	Moderate
Strike a Light	Moderate	Moderate
Tantangara	Low	Low

4.2.5 Step 5 Field Assessments of Priority Management Units

Field assessments were completed in March 2012 for sites within the Management Units (ranked as the highest Erosion Risk).

The field assessments utilised a project specific risk assessment framework to assess the relative potential turbidity risks posed to the ACWA Plan area by specific sites. This framework is summarised in the following section.

4.3 Prioritisation process framework

For the purpose of quantifying the risk to the quality of water being extracted for consumptive use at Angle Crossing and the Mt Stromlo Treatment plant, the following risk assessment has been developed:

Risk = Value x Threat x Consequence x Likelihood x Trajectory

The following definition is applied to each component:

Value = Water Quality for human consumptive use. This is the same value for every risk assessment, therefore it is attributed a multiplier of “1”.

Threat = Threat posed by turbidity on water quality. This is the same value for every risk assessment, therefore it is attributed a multiplier of “1”.

Consequence = This rating relates to the consequence of a specific erosion issue on water quality. It considers the size fraction of sediment eroded and volume that is being exported from an eroding area. For example fine silts mobilised are going to have a higher consequence on turbidity than coarse sediment.

Likelihood = This rating relates to the proximity of a specific erosion issue to the water extraction point or the likelihood that a specific stream has the ability to deliver sediment to the water extraction point. Implicit within this is an assessment of sediment connectivity from the area of erosion to the water extraction point.

Trajectory = This rating refers to the level of erosion activity identified at a site and its stage of development. For example, is there evidence that a site is in the early stages of erosion as evident by incision and presence of active headcuts, has it proceeded to the next stage where it is now eroding its banks or is the evidence that the site has reached a quasi stable state.

Each of these items can be multiplied to give a risk rating for each site which can be used to determine a priority between specific sites. The higher the risk score, the higher the priority of a specific site or issue.

The assessments completed in this project were undertaken by specialists experienced in the assessment of erosion. Although the risk framework presented is a useful guidance tool, all future sites should be assessed with the assistance of an experienced practitioner.

4.4 Consequence Ratings

The following consequence ratings have been allocated for the ACWA project, and are used as the basis for the comparison of sites specific to this project. The consequence ratings consider three elements, size of sediment, volume of sediment generated and extent of erosion at the site:

5 = Catastrophic – Fine sediment, large volume, erosion over several 100 m or kms
4 = Major – Fine sediment, large volume, localised erosion
3 = Moderate – Fine sediment, moderate volume, localised erosion
2 = Minor – Fine sediment/small volume or coarse sediment
1 = Insignificant - Coarse sediment

4.5 Likelihood Ratings

The following likelihood ratings have been allocated for the ACWA project:
5 = Almost certain – High connectivity, close proximity to extraction point
4 = Likely - High connectivity, direct input into major waterway
3 = Moderate - Moderate connectivity
2 = Unlikely - Low sediment connectivity, high potential for sediment storage
1 = Rare – Disconnected from tributary and major waterway

4.6 Trajectory Ratings

The following trajectory ratings have been allocated for the ACWA project:
5 = Early degradation phase – Stream incising bed, active headcuts
4 = Degradation and widening – Bed still incising and banks also eroding (vertical or undercut)
3 = Widening and aggradation – Bed aggrading, erosion of banks (vertical or undercut)
2 = Partially stabilised – Toe of banks and bed partially stabilised with vegetation
1 = Stabilised – Stable channel configuration

Sites with trajectory ratings of 4 or 5 have the potential to generate large volumes of sediment rapidly in the short term. Sites with trajectory ratings of 3 and 2 may still generate sediment loads, but the threat is reduced as the site is approaching a more stable condition.

These trajectory ratings directly link to the conceptual model of erosion processes, the basis of these ratings is discussed further in chapter 3.

As listed in section 4.3, ***Risk = Value x Threat x Consequence x Likelihood x Trajectory***

If value and threat are both assigned a value of 1, Likelihood and Consequence ratings are obtained from sections 4.4 and 4.5, depending on the waterway in question, Trajectory remains the only other variable. Once Trajectory is applied, the following risk scores have been given specific priorities to enable relative comparison of risk between sites (Table 13).

Table 13 Relative risk rankings

Risk	Risk Score	Number of sites
Extreme	64-125	12
Very High	43-63	8
High	31-42	6
Moderate	15-30	16
Low	<15	15