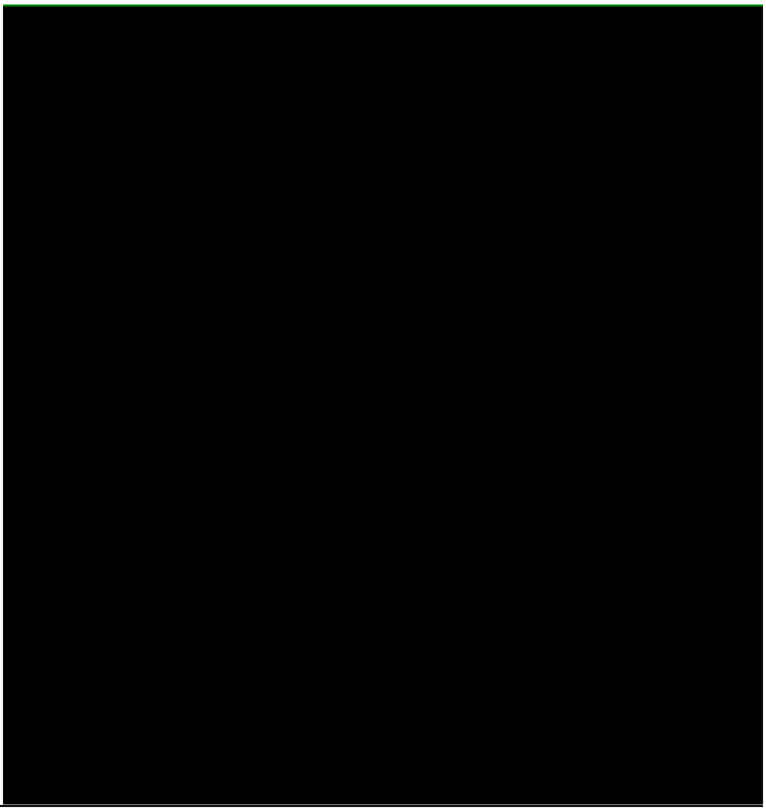
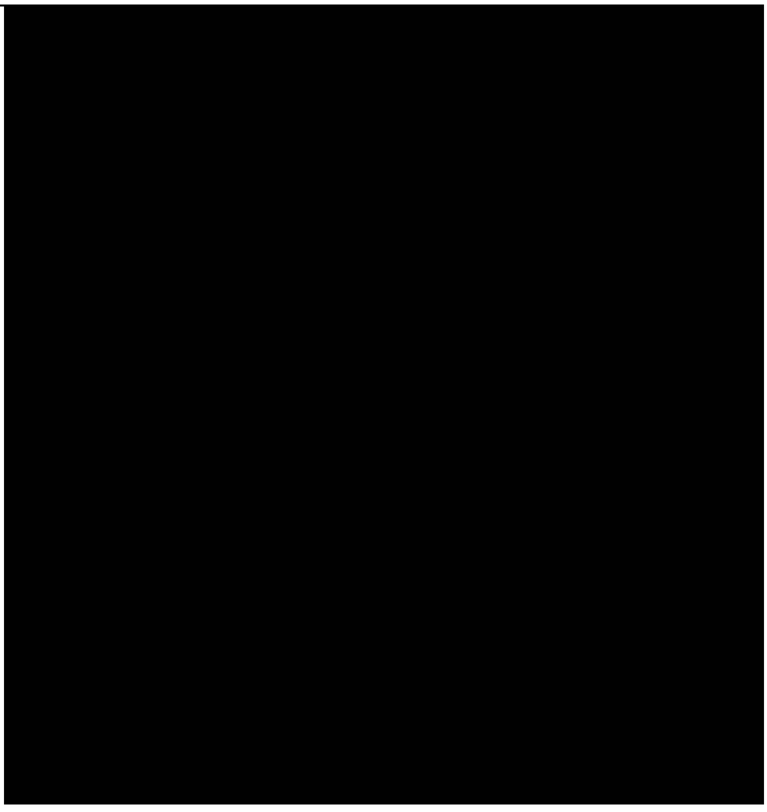


Hydrology of the Eden CRA Region

A report for the NSW CRA/RFA Steering Committee

April 1998



HYDROLOGY OF THE EDEN CRA REGION

BUREAU OF RESOURCE SCIENCES

A report undertaken for the NSW CRA/RFA Steering Committee
project number NE 06/ES
April 1998

Report Status

This report has been prepared as a working paper for the NSW CRA/RFA Steering Committee under the direction of the Economic and Social Technical Committee. It is recognised that it may contain errors that require corrections but it is released to be consistent with the principle that information related to the comprehensive regional assessment process in New South Wales will be made publicly available.

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This project has been jointly funded by the New South Wales and Commonwealth Governments. The work undertaken within this project has been managed by the joint NSW / Commonwealth CRA/RFA Steering Committee which includes representatives from the NSW and Commonwealth Governments and stakeholder groups.

The project has been overseen and the methodology has been developed through the Economic and Social Technical Committee which includes representatives from the NSW and Commonwealth Governments and stakeholder groups.

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EXECUTIVE SUMMARY

This report has been prepared for the joint Commonwealth/State Steering Committee which oversees the comprehensive regional assessments of forests in New South Wales.

The comprehensive regional assessments (CRAs) provide the scientific basis on which the State and Commonwealth governments will sign regional forest agreements (RFAs) for the major forests of New South Wales. These agreements will determine the future of the State's forests, providing a balance between conservation and ecologically sustainable use of forest resources.

This report was undertaken to assess effects of harvesting on catchment hydrology. Changes in land use and land cover alter the water balance of catchments, altering water quality and varying water quantity temporally and spatially. Where catchments are used for several purposes (including recreation/tourism, forest harvesting, agriculture, grazing and National Parks) it is difficult to attribute processes and responses to specific land use practices. However, in the Eden Management Area, research has quantitatively described hydrologic responses to land use, with particular reference to forest management.

The evidence suggests that agricultural land is a major source of sediments in response to soil disturbance and compaction. Clearing for agriculture has long-term and broad-scale effects on catchment hydrology because of the relatively permanent removal of the tree canopy, the discouragement of regrowth, and the replacement of native perennial grasses with shallow-rooting annual grasses. Intensive agricultural practices also represent significant point sources of nutrients from sites such as feed lots or dairies.

The effects of forest harvesting on water quality vary according to local site conditions, including catchment area, percentage forest cover, roading infrastructure, frequency of prescribed burning and type of harvesting operation. The major sediment source in forested catchments is the roading infrastructure (including snig tracks and landings). It has been shown that snig tracks generate seven times more surface runoff and 20 times more sediment per unit area than the general harvesting area (Croke *et al.*, 1997). Sediment losses from roads vary according to harvesting practices (which determine how long roads remain open) and road design and maintenance.

Catchment water yields vary in response to forest management practices. Changes in yield have been quantified in a number of catchments in the Eden Management Area and study results indicate that total runoff returns to pre-treatment levels within four years, or within eight years where both logging and fire occur (Mackay and Cornish, 1988). Predicted maximum changes in runoff from forest operations in representative catchments are relatively small even when up to one quarter of the catchment is harvested. Further studies indicate that where less than 20 per cent of effective vegetation is removed, no initial increase in catchment yield occurs (Cornish, 1993). Thus, the magnitude of change in catchment yield is proportional to the area harvested. Furthermore, whilst impacts may be expressed at a local or sub-catchment scale, they may be buffered out at a catchment scale.

Only the Bega and Towamba catchments have agricultural production that relies on irrigation from rivers within the catchment. The Bega catchment has 6.2 per cent of its area as State Forest potentially available for harvesting, and the Towamba catchment has up to 29 per cent of its total area available for harvesting. On a catchment scale, harvesting within these two catchments is unlikely to have any downstream effects on agricultural production due to the small area involved within the Bega catchment, and to the limited requirements for irrigation water within the Towamba catchment. On a sub-catchment scale effects cannot be determined due to the lack of available research.

Comprehensive management of forested catchments is implemented under a raft of legislation and policy which mitigates impacts of forest harvesting on water values. In addition, on-going scientific research is assessing potential impacts of forest management activities on water values.

1. HYDROLOGICAL SETTING

1.1 INTRODUCTION

A reliable supply of water that meets quality standards for a range of uses is essential for maintaining natural environments, and for domestic, agricultural, industrial and recreational uses. However, water yield and quality are sensitive to changes in land cover, catchment use and management. In particular, large scale timber harvesting has the potential to affect water quality and quantity in some forested catchments. The relationship between water, forests and forest use is complex, and is based both on extrinsic factors such as climate, geology, soils, and topography as well as intrinsic factors such as land cover change. Based on the interactions of these factors, a total catchment perspective is presented by providing background information relating to land tenure and use. Moreover, the region is characterised in terms of climate, topography, geology, hydrogeology, soils, vegetation and aquatic ecosystems. This contextual approach emphasises the linkages between systems and processes, and permits identification of potentially hazardous or high risk areas. An overview of water resources and uses is given in this report, including an assessment of the relationship between land use and water values with specific reference to sedimentation issues in the Genoa River catchment.

1.2 CLIMATE

The Eden study area experiences a cool temperate climate with cool to cold winters and mild summers. Temperatures are moderate in response to coastal effects, although frosts, fog and occasional snowfalls are associated with high elevations in the western section of the area during winter. Rainfall varies throughout the region as a function of distance from the coast and orographic effects. In terms of the latter, the highest rainfall is associated with western slopes of higher elevations in the South Coast Range while rain shadow effects are noticeable east of the Alps in the Tablelands and in the central valleys of the Bega and Towamba catchments. Monthly rainfall is highly variable with no well defined seasonality. Long term climatic data suggest that the driest period of the year extends from midwinter to early spring, and the highest from midsummer to early winter. Episodic depressions and frontal systems moving from the west bring rain during the winter-spring, and the intrusion of moist air from northern Australia causes rainfall and thunderstorm activity in the summer. Summer rain generally comprises short duration, high intensity events. A summary of climatic data is provided in Table 1.

TABLE 1 CLIMATIC DATA FOR THE EDEN REGION

Station	Elevation (m)	Mean daily maximum temp (Feb)	Mean daily minimum temp (July)	Mean Annual Rainfall (mm)	Mean annual no. of Frosts
Merimbula Airport	2	24.7	4.0	811	-
Bega composite	11	27.2	1.0	879	30.7
Green Mitsubishi Cape Lighthouse	18	22.1	8.3	751	-
Nalbaugh State Forest	675	23.8	0.1	1184	-
Bombala composite	742	25.1	-1.3	649	72.4
Nimmitabel P.O.	1075	22.8	-1.8	705	92.3

After Eden *SFNSW, 1994*

Climatic factors relevant to forest hydrology include impacts of rainfall frequency, intensity and duration on soil erosion and the frequency and duration of drought conditions. The spatial distribution of rainfall erosivity indicates annual rainfall erosivity ranges from a low of 2000-3000MJ mm^{-1} in the south to a high of >5000MJ mm $^{-1}$ in the Wadbilliga National Park in the north, with most of the region having values of 3000-4000MJ mm^{-1}.

1.3 TOPOGRAPHY

The Eden forest region comprises a coastal zone of gently undulating country with elevations up to 80m, rising through rolling, dissected foothills of moderate relief with up to 350m elevation and hinterlands associated with granite outcrops. The Great Escarpment is an erosional feature which demarcates the coastal area from the inland plateau. This escarpment is associated with a dissected hilly landscape with elevations up to 1300m and includes sandstone plateau in portions of the Wadbilliga, Nungatta and Mount Imlay National Parks. Immediately west of the escarpment, the country is marked by undulating or ridge country, which is dominated by granite. This mountain range (the South Coast Range) trends north northwest defining a major drainage divide and forming part of the Great Divide. Further inland, where the drainage system flows in a generally westerly direction, high elevation undulating country comprises part of the Monaro Tablelands, which is a low relief, low rainfall area of grassland or open woodland.

1.4 GEOLOGY

The basement rocks of the region comprise Ordovician metasediments including interbedded greywackes and shales metamorphosed to low grade phylllites. Outcrops occur in coastal forests north of Bega, in the western portion of the Bondi State Forest, and in a north-south trending zone south of Eden; encompassing the area between Mount Imlay, Timbillica Hill and the Nadgee

Range. Deformation is complex, with north south trending, open to tight fold structure. The Bega Granite intrudes the metasediments, imposing thermal metamorphism along boundaries between the granite and country rock. Where this occurs, the metasediments have been altered to hornfels and schist producing relatively resistant contact aureoles up to one kilometre from the pluton. The metamorphosed metasediments can also occur as north-south trending screens, as roof pendants overlying the granite, or can separate individual plutons within the batholith. The Bega Batholith, which has been ascribed to the Late Silurian to Early Devonian, consists of 66 separate intrusions and covers approximately 45 per cent of the Eden forest region.

The Ordovician rocks are overlain by Late Devonian volcanic and sedimentary rocks. To the east of the Bega Batholith, Late Devonian Volcanics outcrop. These rocks are grouped as the Boyd Volcanic Complex, a bimodal suite including silicic volcanics (previously named the Eden Rhyolite) as rhyolitic domes, dykes and sills, lenticle-tuffs, mass-flow breccias, basalt and scoria and basic volcanics (previously the Lochiel Formation) as tuffs, ignimbrites and swarm dykes of porphyry. These silicic and mafic volcanics are complexly intercalated, with the silicic volcanics underlying, overlying and intruding the mafic volcanics which tend to be associated with former stream beds (Powell, 1983).

Small plutons of Late Devonian granite were derived from the same magma as the volcanics and are associated with the Boyd Volcanic Complex. It is believed that they formed from the partial melting of the crust after production of an earlier granite (Collins *et al.*, 1982). The geochemistry of these granites differs from the Bega Batholith being more sodium rich and containing less magnesium, calcium and phosphorous. The granites intrude the Ordovician and Devonian sedimentary rocks at Mumbulla, Doctor George Mountain, north and north-east of Bega respectively, and at Little Brown Mountain north of Bemboka. Granites located south of Eden are assigned to the Gabo Suite (including the Watergums Adamellite, Nagha Adamellite, Monga and Wangrah Granites), and the granites to the north of Eden are named the Mumbulla Suite.

The sedimentary sequence, the Merimbula Group and frequently referred to as red beds, are fluvial deposits which include conglomerates, sandstones and shales which outcrop as subhorizontal strata and occur in three main areas, often forming the rugged scenic highlands within the Wadbilliga and Mount Imlay National Parks: the Budawang fold structure west of Bodalla; the Wadbilliga National Park-Bemboka State Forest area; and, the Eden-Merimbula district. Outcrops also occur on prominent topographic highs including Mount Imlay, Timbillica Hill and Nungatta Plateau. These sediments were derived from weathering and erosion of the immediately underlying Boyd Volcanic Complex and from the Eden Granite (Powell, 1983). Upper sequences represent very fine grained intertidal deposits.

A Jurassic nephaline syenite intrusion has been described at Jingera Rock and Burragate Peak within the Egan Peaks Nature Reserve, and has been called the Jingera Complex. The complex is an elliptical shape 5.5km long and 1km wide and intrudes the Bega Batholith and Ordovician metasediments.

During the Tertiary, unconsolidated sediments as sands and gravels were deposited in the coastal lowlands in response to extensive erosion in the upper topographic regions. Deposits of these sediments occur in sections of the Nadgee, East Boyd and Nullica State Forests and cover discontinuous areas of flat to undulating lowlands along the coast to a distance of up to 4km inland with the exception of the Towamba Valley where they extend much further.

The extrusion of plateau basalts, the Monaro Volcanics, also occurred during the Tertiary over extensive areas in the Nimmitabel district. These basalts represent a Tertiary lava field which erupted from a number of vents, and now form a tableland of low relief, bisected by a north-west trending series of remnant volcanic plugs (the Monaro Range).

Recent alluvial and colluvial deposits are associated with the modern drainage network, with deep alluvium occurring in the downstream sectors of the major river valleys as fluvio-deltaic deposits, valley fill, tidal delta and backbarrier deposits. On hillslopes and along valley margins, alluvial fan sequences are evident.

Large scale faults extending for tens of kilometres are numerous in the region and include:

- The Edrom Fault, trending north-east just south of Eden, offsets the boundary between the Boyd Volcanic Complex and the Ordovician metasediments (Adaminaby Group);
- The Burragate Fault which extends 77km in a north-east direction from the Cann Valley Highway in the south to Tathra. This fault is defined largely by offsets in boundaries between granite and the Ordovician metasediments, and by a major offset in the course of the Towamba River at Burragate;
- The Tantawangalo Fault, trending north-east from near the Cann Valley Highway in the south to the Beauty Point-Wallagra Lake area in the north-east, a distance of approximately 82km. A section of the Bega River is aligned to this fault upstream of Tantawangalo; and
- The north-west trending Towamba Lineament which generally defines the alignment of the Towamba River Valley.

These structural features impose local controls on groundwater recharge and discharge in response to intensive fracturing and shearing of the rock together with deep, strong weathering.

1.5 HYDROGEOLOGY

The Eden Forest Region is underlain by consolidated rocks, a large proportion of which are massive igneous intrusives and extrusives. Water in these consolidated rocks occurs within the joints of the rock material. The degree of fracturing of the rock mass is highly variable, being a function of deformational history. Porosity of the rock mass is also a function of weathering, which is greatest along fracture planes, at shallow depths and in association with faults. Higher groundwater yields will therefore be associated with rock boundaries and major lineaments and faults. Ranges of groundwater yields, according to lithology, are provided in Table 2.

TABLE 2 GROUNDWATER YIELD AND QUALITY IN UNCONSOLIDATED SEDIMENTS AND FRACTURED ROCK AQUIFERS IN THE BEGA CATCHMENT

Unit	Yield (L s^{-1})	Salinity (mg L^{-1})
Quaternary alluvium	0.8 - 40	100 - 8000
Tertiary sediments	0.3 - 2	223 - 7935
Basalt	0.15 - 3	n/a
Merimbula Formation	0.63	n/a
Bega Granite	0 - 3.8	425 - 2700
Ordovician metasediments	0.2 - 1.8	n/a

After Sundararamayya, 1983

Small areas of Tertiary deposits and Recent alluvium comprising flats in the downstream sections of the major rivers have most potential for low salinity/high yield groundwater supplies suitable for industrial, irrigation and municipal uses (including the Bega and Brogo Rivers at Bega, the Towamba River between Kiah and Towamba, and the lowest reaches of the Wonboyn River). At Bega, approximately 1400 ML a^{-1} are extracted from these aquifers for urban water supplies to Bega and Tathra, and upstream of Kiah, groundwater supplements the Tantawangalo Scheme which supplies Eden and a number of smaller towns (Water Resources Commission, NSW, 1984). The extractable storage of groundwater in the alluvium has been estimated at 14,300ML (Sundaramayya, 1983).

1.6 SOILS

Soil formation is dependent on the factors of geology, climate, topography, time and biogenic activity. Since soil mineralogy, texture and fabric are all defined by geology, the description of soils here is based on soil-rock associations. The response of the soils to various forms of disturbance including compaction and exposure of highly erodible subsoils by vehicles and logging operations depends on soil physical, chemical and engineering properties. The processes of sediment detachment, transportation and deposition depend largely on clay mineralogy and particle size, all other factors being constant. Thus the distance sediments are transported and the percentage entrained by vegetation in buffer strips will be a function of particle size and aggregate stability when wetted, soil infiltration capacity, hydraulic conductivity and the degree to which flows are channelised. These properties will also influence the proportion of eroded material transported as suspended sediments or bedload. Whilst suspended sediments may impact turbidity and potability of water, sediments as bedload material impact on macroinvertebrates and fish. Furthermore, soil physical properties including shear strength, angle of internal friction and cohesion will define slope stability and mechanisms of bank collapse and gully erosion. Duplex soils developed on coarse grained acid volcanic or granitic parent material often have a thixotropic A2 horizon (Beavis and Beavis, 1996). Thixotropy, whereby mechanical agitation of a saturated soil by machinery, vehicles or animals produces liquefaction of the soil, has serious implications for erosion where soil disturbance occurs. Knowledge of the geology and soils of an area are therefore integral to forestry management practices.

Previous work has described soil landscapes, soil types and representative areas within the study area (SFNSW EIS,1994) and has identified soil-rock associations (Table 3).

The areal proportion of these soil types within State Forests of the Eden Forest Region establishes that the dominant soil types are red and yellow podzolic soils (26.1 per cent), stony yellow podzolic soils (22.2 per cent), stony red earths and yellow podzolic soils (16.3 per cent), sandy red earths and yellow earths (13.6 per cent). This distribution indicates that a significant proportion of the area under forest has course grained, texture contrast soils which are moderately to highly erodible in response to both surface runoff and throughflow processes. In particular, it should be noted that soils developed on granitic and/or silicic intrusive parent material are highly erodible due to clay dispersion and thixotropy when saturated (Beavis and Beavis, 1997). Furthermore, soils developed on the Ordovician metasediments may have low shear strength and are therefore associated with failure by rotational slumping, and sliding (Beavis, 1992).

TABLE 3 SOIL LANDSCAPES, TOPOGRAPHY, SOIL TYPES AND REPRESENTATIVE SITES IN THE EDEN FOREST REGION

Soil landscape	Topography	Soil types	Representative sites
Recent sediments			
Pambula	Undulating rises on coastal lowlands	Lateritic podzolics	Ben Boyd and Mimosa NP
Nunnock Swamp	Peat bogs and swamps, 1075-1085m asl	Yellow earths, brown clays and acid peat soils	Wadbilliga NP
Igneous extrusive rocks			
Bournda	Rolling low hills. 0-570m asl	Yellow podzolics and lithosols	Mumbulla SF
Mount Darragh	Rolling low hills 640-964m asl	Kraznozems and gleyed podzolics, lithosols and shallow kraznozems	Tantawangalo SF
Igneous intrusive rocks			
Biamanga	Rolling low hills, 30300m asl	Red and yellow podzolics, sandy red and yellow earths	Mumbulla SF
Big Badja	Gently undulating low hills, 1030-1157m asl	Earthy sands and yellow podzolics	Wadbilliga National Park
Glenbog-Coolangubra	Rolling to steep low hills, 200-960m asl	Lithosols and earthy sands	Tantawangalo, Glenbog, Cathcart, Coolangubra SF
Tantawangalo Escarpment	Steep hills and mountains, 200-935m asl	Lithosols, sandy earths and earthy sands	Tantawangalo, Glenbog, Cathcart, Coolangubra SF
Mumbulla Mountain	Steep hills, 100-774m asl	Lithosols and sandy earths	Murrah and Mumbulla SF
Yambulla	Rolling low hills, 280-560m asl	Red and yellow podzolics, sandy red and yellow earths	Yambulla SF
Jingo Creek	Rolling low hills, 250-575m asl	Red and yellow podzolics, sandy red and yellow earths, lithosols and earthy sands	Nullica SF
Devonian sediments			
Pigeon Box Mountain	Steep hills and mountains, 160-1013m asl	Stony red earths, yellow podzolics and lithosols	Bembooka SF
Yellow Pinch	Rolling to steep hills, 0-774m asl	Lithosols, stony red earths, red and yellow earths	Yurammie, Gnupa, Murrah SF
Ordovician metasediments			
Brogo Pass	Rolling to steep hills, 10-300m asl	Lithosols and stony red earths	Brogo Pass to northeast of Wolumla, freehold land
Murrah	Coastal Ranges, 0-436m asl	Stony yellow podzolics, stony red earths and yellow podzolics	Murrah, Mumbulla, Tanja SF

1.7 VEGETATION

The main forest associations (referred to in the Eden EIS, 1994, as forest leagues) which occur in the Eden FMA include Stringybark/Silvertop Ash, Messmate/Gum, Brown Barrel, Spotted Gum and Rainforest. The Stringybark/ Silvertop Ash is concentrated in the coastal forests of the study area. The messmate/gum association on the other hand are found on the tablelands in the Eden management area and in the gullies of the coastal forests. Brown Barrel also occurs on the tablelands particularly in the northern parts of the study area. Spotted Gum is found in the coastal forests between Bega and Bermagui. Small patches of rainforest are also found in the deep gully areas of the study area. (SFNSW, 1994). The Eden vegetation is described more fully as commercial forest types within DPIE (1998).

Within these broad categories there are 68 forest types which incorporate understorey (FCNSW, 1989). These forest types are largely based on their interaction with topography, soils and microclimate. The components of the forest structure are equally as important in relation to water quality and runoff as the species which makes up the overstorey.

Vegetation cover, in particular ground cover, is very important as it provides 'hydraulic roughness', lowering the velocity of the surface flow, increasing detention and depression storage which allows more water to be infiltrated (Croke *et al*., 1997). In effect vegetation cover will reduce the speed of runoff, which in turn reduces the sediment carried with it.

Understorey species that occur within the EMA are more variable than the overstorey species. One study carried out in the Tantawangalo Research Catchment describes species within the middle and understorey re-growth in this catchment including *Bedfordia arborescens*, *Pommaderris spp*., and *Olearia spp*., various *Acacia* species, *Tasmania* and *Bursaria*, *Exocarpus*, *Senecio* and *Goodenia*, *Gahnia spp*., *Blechnum nudum* and *Polystichum spp*., as well as many types of herbs and grasses. These particular species were identified by Ryan, Williams and Mackay (1988) for the Tantawangalo Research Catchments (Dodson *et al.*, 1988). This is a fairly typical description of the wet sclerophyll Messmate/Brown Barrel/Gum league which occupies 40 per cent of the EMA. The dry sclerophyll Silvertop Ash/Stringybark league also occupies 40 per cent of the EMA and the species listed in Harper and Lacey (1997) for the Yambulla catchments are typical of this league. In a study carried out by Croke *et al.*(1997), nine sites were chosen in which *Bedfordia arborescens* (Blanket Bush), *Olearia argophylla* (Musk Daisy Bush) and *Cyathea australis* (Tree fern) were identified as middle storey regrowth. Further reference to the vegetation resource within the EMA can be found in Section 3: 'Forest Resource' of this report.

1.8 CATCHMENTS AND LAND USE

Land tenure in the Eden Forest Region is largely a function of topography, soils and population distribution. Consequently, cleared, partially cleared, agricultural and/or freehold land is generally associated with landforms in the tablelands, coastal hills and valleys which are characterised by moderate topography and better soils. Farming comprises sheep and cattle grazing, dairying and cropping. Furthermore, major settlements are located along the coast line and in the major valleys (Bega, Bemboka and Towamba Rivers). These agricultural, pastoral and urban areas represent actual or potential sources of sediments, nutrients and pollutants to the drainage network.

In contrast, in the steeper areas of the foothills and escarpment, forests are used and managed for forestry and conservation. The disturbance of these areas during logging operations has the potential to impact on downstream water quality and yield. The distribution of land tenure within the region is summarised in Table 4.

TABLE 4 LAND TENURE IN THE EDEN FOREST REGION

Land Tenure	Gross area (ha)
State forest and flora reserves in the EMA	198,315
Crown lands in the EMA	22,846
Plantations (gross)	42,008
National park + nature reserve	213,205
Private and other	337,880
Total	**814,254**

(figures prepared for Eden CRA, June 1997, Cornish pers.comm)

More detailed analysis of the spatial distribution of land tenure within the region, on a catchment basis (Table 5), indicates that some catchments are almost entirely forested (Wallagaraugh catchment 91 per cent State forest) whilst others have minimal coverage (Bega catchment 8 per cent State forest). The relative distribution of land tenure within catchments will have some significance in terms of impacts of site specific land cover changes on water yield and quality, however, the extent of these impacts has not been investigated.

TABLE 5 SPATIAL DISTRIBUTION OF LAND TENURE ON A CATCHMENT BASIS IN THE EDEN FOREST REGION

Catchments	State Forests a) % in catchment b) % in CRA catchment			National parks and nature reserves (ha)	Other Crown lands and leasehold (ha)	Private property (ha)	Catchment area in Eden CRA (ha)	Total Catchment area (ha)
	a)	b)	(ha)					
Snowy	24		31 977	4478	6 733	88 473	131 662	unknown
Coastal North	21		17 686	28 357	1 604	38 132	85 780	unknown
Murrumbidgee	1		326	615	7 541	38 258	46 740	unknown
Bega	8	8	15 763	79 967	2 313	111 234	209 277	209 277
Towamba	38	38	38 539	31 951	667	31 433	102 590	102 603
Coastal Central	39	39	23 022	14 845	3 018	18 622	59 507	59 507
Coastal South	51	41	32 388	28 802	254	2 115	63 559	79 795
Wallagaraugh	91	83	53 658	4 593	0	796	59 047	65 035
Genoa	50	23	25 987	18 402	197	7 857	52 443	114 476
Cann River	92		937	81	0	5	1 023	unknown
Unknown	2		39	1 114	519	954	2 627	5253
Total area (ha)			**240 323**	**213 205**	**22 846**	**337 880**	**814 254**	

1.9 SURFACE WATER RESOURCES

The Australian Water Resources Commission (AWRC) has divided Australia into twelve Drainage Divisions which are sub-divided into basins. The Eden Forest Region is within the Murray-Darling Division and South East Coast Division and extends across four basins:

The **Bega River Basin** (#19 AWRC) - including the Bega, Bemboka and Brogo Rivers, Tantawangalo Creek and their tributaries;

The **Towamba River Basin** (#20 AWRC) - including the Towamba River, Merrica River, Merimbula and Pambula Creeks and their tributaries; and

The northern section of the **East Gippsland Basin** (#21 AWRC) - including the Wallagaraugh River, the Genoa River and their tributaries.

The eastern section of the Snowy River Basin (#22 AWRC) including the Delegate, Snowy, Little Plains and Bombala Rivers and their tributaries.

Estimates of the catchment area, mean annual streamflow and flow variability as a percentage of the mean for the Bega and Towamba basins is provided in Table 6. Current water use in these catchments is summarised in Table 7.

Town water supplies in the study area depend on surface water and groundwater. Details of supplies for the Bega catchment are as follows in Table 8.

TABLE 6 MEAN ANNUAL STREAMFLOW OF RIVER BASINS

Basin	Area (km^2)	Mean annual streamflow (ML)	Streamflow Variability (%)
Bega	2850	940 000	9-360
Towamba	2200	530 000	46-200 (at Eden)

DLWC, 1994

TABLE 7 CURRENT WATER USE

Basin	Town water supplies (ML)	Irrigation supplies (ML)	Other (ML)	Current water use (ML per year) 1991/2	Number of irrigation licences
Bega	3000	14000	400	17400	160
Towamba	500	200	100	700	20
Total	**3500**	**14200**	**500**	**18100**	**180**

DLWC, 1994

TABLE 8: TOWN WATER SUPPLIES IN THE EDEN MANAGEMENT AREA

Town/Scheme	Source of Water Supply			Annual consumption 1985 (ML)	Projected Annual consumption 2005 (ML)
	Stream	Dam	Groundwater		
Bermagui Scheme	Pipeline from Brogo River	Weir on Couria Creek; Tilba Dam	×	300	642
Cobargo	Connection to Brogo-Bermagui pipeline	Illawamabra Dam on Wandella Creek		50	58
Quaama	Connection to Brogo-Bermagui pipeline			10	12
Bega	New reticulation system	Brogo Dam	×	1800	2550
Bemboka	Bemboka River			30	38
Tantawangalo Scheme		Weir on Tantawangalo Creek; Yellow Pinch Dam; Ben Boyd Dam	×	1900	4657
Total				**4090**	**7957**

Interdepartmental Committee (1985)

1.10 WATER USE AND ECONOMIC PROFILE

The data in Tables 7 and 8 demonstrate that urban and irrigation uses of water represent a small proportion of total catchment yields. Furthermore, surface water supplies are supplemented by groundwater in a number of catchments.

Data relating to the economic value of water are limited for the study area. In the Bega and Eurobodalla shires there are 6000 hectares of irrigated land using water diverted from the Brogo, Bega, Bemboka, Tantawangalo and Bodalla Rivers. Many smaller areas are irrigated, although these are less significant in terms of water use. The Bemboka Catchment study (Gutteridge Haskens and Davey, 1997) estimated that for the Bemboka catchment above Moran's Crossing some 1400ha of land was irrigated. It was estimated that annual water use was between 4.5 and 5 ml/ha/yr.

Pasture is irrigated only when it is required during low rainfall periods to grow feed for stock. Preliminary analyses of costs and benefits of dryland versus irrigated pasture indicate that, whilst there are significant differences in costs, profits are comparable (Kemp, pers. comm.). In general terms, 1 ML of water is used to produce 1 tonne of dry food, however, this does not translate very well for agriculture. It is difficult to compare irrigated and dryland businesses. Irrigated businesses can produce up to 20 tonnes of dry matter/ha/yr in comparison to 6-7 tonnes/ha/yr for dry land. This translates into running 3 cows per hectare on irrigated and 1 cow/ha on dry land, receiving 5000 litres of milk/cow. These benefits to dairying, in response to irrigation, represent surrogate economic values for water. However, since farms in the shire only irrigate during times when rainfall is low, it is difficult to determine what the actual benefit is to individual farmers within the area. (Kemp, pers. comm.)

The areas available for harvesting over the long term form a significant proportion of some catchments especially the Wallagaraugh. Until existing experimental data are analysed in detail it is not possible to provide more than conjectures on water yield effects except for immediate post logging increases. Cornish (1997) has found that for the Wallagaraugh catchment water yield increases after harvesting are detectable at a catchment scale.

An assessment of water uses within the CRA region shows agricultural use of irrigation water in only the Bega and Towamba catchments (see Table 7). The Bega catchment has only 8 per cent State Forest of which only 6.2 per cent is available for harvesting (see Chapter 3) so is unlikely to have any significant effect on water quantity for irrigation. The Towamba catchment irrigation requirements are well below low stream flow levels (see Table 7) and with approximately 29 per cent of the catchment available for timber harvesting it is unlikely that there would be any effect on downstream water requirements.

1.11 WATER QUALITY

The physical, chemical and biological characteristics of water determine its quality. Any significant loss of quality has a deleterious effect on aquatic ecosystems and reduces the value of the resource. Catchment conditions and water quality generally coincide. Undisturbed, forested catchments generally retain high water quality while, in contrast, agricultural and urban environments and disturbed forest/plantations have lowered water quality. Land use practices resulting in erosion and the transport of nutrients, urban runoff or point source discharges of pollutants are major causes of poor water quality in stream networks. Monitoring in the Eden Management Area indicates that water quality is high in the area, in terms of electrical conductivity, turbidity and pH. On the basis of monitoring results, water meets standard requirements for recreational activities, aquatic ecosystems, aesthetics and for domestic, agricultural and urban use (Gippel, 1997). However, the monitoring network is sparse with only 5 continuous stations. Consequently, the data may not reflect fluctuations in quality associated with large events. Furthermore, results can be biased if sampling is largely occurring during baseflow conditions, when the water quality is good (Gippel, 1997), which can result in underestimates of turbidity. However, research at a subcatchment and local level provides indicators of hydrological responses to climate and land use/land cover changes. Further development of the monitoring system is currently underway.

1.12 AQUATIC ECOSYSTEMS

The aquatic habitats that are of main concern in the Eden Management Area (EMA) are those of the riverine habitat which occur downstream of forestry operations in State forests. In the Eden Management Area the majority of aquatic habitats of the upland sections of streams are seen to be more structurally diverse than those further down the escarpment in the areas along the coast. Here, the upland streams tend to provide more microhabitats in the cobble and gravel substratum than that of the lower streams which have substratums made up of gravel, sand and silts. In some instances in the upland streams, streambeds consist of bedrock, with some stone and gravel material being confined to pool reaches and backwater areas. Stream habitats also develop structural diversity in the form of large woody debris, twigs, leaves, bark, and fine particulate matter which is formed from the decomposition of leaves and detritus. (SFNSW, 1994).

Aquatic inhabitants of the riffle reaches in upland streams display higher species diversity and community structure, as well as being more sensitive to changes in water quality. The benthic macroinvertebrates are the best indicators of the effects of forestry operations on aquatic environments as they are considered more sensitive to the changes in water quality due to their relatively reduced mobility (SFNSW, 1994).

TABLE 9 AQUATIC INHABITANTS OF STREAMS WITHIN THE EMA

Taxonomic Group	No. of species
Macroinvertebrate fauna	81
Fish fauna	52
Mammals	3
Amphibians	24
Reptiles	9

Source: Collated from data within the Eden EIS (SFNSW, 1994)

Many EMA streams on private land have lost their indigenous vegetation and in many cases it has been replaced by willows. Indigenous vegetation provides a continuous food source to detrivores in contrast to willows where the lack of litter for most years in a willow-bordered stream affects biodiversity (O’Shaughnessy, pers. comm.).

1.13 ENVIRONMENT AND HERITAGE VALUES

In addition to social and economic values, healthy rivers have an intrinsic environmental value. As discussed in section 2.1.11, the stream network within the Eden region provides habitat for numerous fauna. Changes to water yield and quality by human activity can modify riverine ecosystems. However, environmental values can be maintained or restored by controlled releases from water storages to ensure that flows are oxygenated and are at ambient temperatures. Further advantages involve the maintenance of minimum flows. Within the region, Brogo Dam has an uncontrolled outlet. However, at present there are no formal environmental flow guidelines for the rivers of the region. The Department of Land and Water Conservation is currently establishing environmental flow regimes.

2. RELATIONSHIP BETWEEN LAND USE AND CATCHMENT AND WATER VALUES

2.1 AGRICULTURE

2.1.1 Water Quantity

The expansion of agriculture since European settlement has been associated with extensive clearing of forests and woodland and subsequent improvement of native grassland with exotic species and the application of superphosphate. These land cover changes have a number of immediate impacts on catchment hydrology: Removal of the tree canopy reduces interception losses (Langford *et al.* 1982, Ruprecht and Schofield 1989) and increases surface runoff. Replacement of deep rooting native pasture by shallow rooting improved pasture reduces the extraction of soil moisture by plants, particularly during dry periods leading to relatively higher runoff rates and aquifer recharge. Subsequent increases in streamflow may be correlated with expansion of the groundwater discharge area.

However, there is evidence to suggest that introduced plant species transpire moisture at greater rates than native species (Carbon *et al.* 1982), thereby reducing runoff. This is compounded by the inverse relationship between infiltration rates and intensity of grazing as a function of soil compaction. Furthermore, the percentage groundcover in cropping conditions, which varies temporally, is significant. Bare or fallow ground creates the most runoff, whilst closely grown crops result in least runoff (Ring and Fisher, 1985).

In response to land degradation problems, often initiated by clearing and inappropriate management practices, farmers have been encouraged by State soil conservation authorities to construct contour banks, grassed waterways and farm dams to form integrated erosion control networks. These structures modify catchment surfaces, impede the movement of water within a catchment, and ultimately reduce stormflow and streamflow. In a catchment with conservation treatments including perennial pasture, three-year crop rotations and extensive contour banking, a 24 per cent reduction in runoff was measured, with the figure almost doubling to 43 per cent for drier periods (Moore and Morgan 1969). Reductions in streamflow in response to the construction of farm dams ranges from 4 per cent to 62 per cent with the effects being most pronounced during low rainfall periods (Ockenden and Kotwicki, 1982, Srikanthan and Neil 1984, Cresswell 1992, Good 1991). Furthermore, the diversion of water for irrigation reduces downstream flow, and can contribute to potential conflicts between users.

2.1.2 Water quality

Agricultural practices which disturb the ground surface include:

clearing

cropping

overgrazing

stock access to streams and drainage lines and their associated saturated zones

fencing,

farm access tracks, and

farm dams

These activities provide conditions for the mobilisation and transport of sediments. Consequently, natural rates of erosion are accelerated, with the most significant increases being associated with cropping where the rate of soil loss can exceed 30 times the natural rate (Neil and Fogarty 1990).

The proportion of sediments that are delivered to the stream network of a catchment is a function of rainfall intensity and duration, slope, soil erodibility, particle size, continuity of the drainage network (the degree of connectivity between the erosion gully network and the fluvial system) and land cover. Sediment transport data (as turbidity or suspended sediment concentrations) are indicators of erosion within a catchment. Water quality data for selected sites within the Eden region provide possible indicative relationships between catchment development and sediment loss (Table 10). However, roading intensity and geology will be further important factors.

TABLE 10 OVERVIEW OF WATER QUALITY FOR SELECTED STREAMS IN THE EDEN STUDY AREA BASED ON LONG TERM DATA

Stream gauging station	Catchment condition	Mean Electrical conductivity (μS cm $^{-1}$)	Mean Turbidity (NTU)
Wallagaraugh River @ Princes Highway	**forested; freehold in local area**	**126**	**8.6**
Wallagaraugh @ Allan Brook Road	**forested**	**114**	**9.4**
Towamba River @ Towamba	**Agricultural and urban**	**137**	**16.4**
McCarthy’s Creek @ Tantawangalo Road	**forested**	**96**	**5.7**
Tantawangalo Creek @ weir	**forested**	**82**	**2.5**

Source: *SFNSW, 1994*

These data are supported by results from water quality monitoring at the Bago State Forest, near Tumbarumba, New South Wales, where median values for turbidity and electrical conductivity have been derived for different land uses and broad geological associations (Table 11). These results further emphasise the need to include geology in catchment/regional characterisation when assessing catchment responses to disturbance.

TABLE 11 MEDIAN VALUES OF TURBIDITY AND ELECTRICAL CONDUCTIVITY ACCORDING TO LAND USE AND LITHOLOGY (AFTER TURNER *ET AL.*, 1996B)

Land Use	Turbidity (NTU)	Electrical conductivity (μS cm $^{-1}$)
Hardwood		
Basalt	2.4	18.5
Other lithologies*	2.0	16.3
Pine Plantations		
Basalt	4.1	45.8
Other lithologies	2.7	18.0
Freehold Cleared	4.9	27.5

* granite, sedimentary, other volcanics

Agriculture can also impact on water quality through the application of agrochemicals including herbicides, pesticides, insecticides, fertilisers, growth promotants, stock pharmaceuticals, ripening agents and supplementary feeds. The use of these chemicals is integral to the reduction of production costs and losses together with increased production and product quality. Further impacts occur in response to the illegal disposing of chemical wastes and containers, and to effluent discharges from piggeries, feedlots and milking sheds. Surface runoff and groundwater recharge contaminated by these chemicals can reduce the water quality of streamflow and the groundwater.

2.2 URBAN/RESIDENTIAL AREAS

The highest populations within the region occur in a number of generally small inland and coastal towns (Table 12. These centres represent point sources of nutrients and pollutants from stormwater. Smaller towns and settlements rely on septic tank systems, and at these settlements stormwater drains can carry kitchen and bathroom sullage. Bega, Bermagui, Tathra, Tura Beach, Merimbula, Pambula Beach, Pambula and Eden are sewered. Effluent from these towns is generally diverted and used to water golf courses, with the exception of Bega, where effluent is diverted to a dairy farm for spray irrigation (R. Luke, Bega Valley Shire Council, pers.comm.). During large rainfall events, the effluent from coastal towns flows into the sea.

TABLE 12 POPULATION OF TOWNS AND VILLAGES IN THE EDEN REGION (1991 CENSUS)

TOWN	**POPULATION**
Bega	4192
Bemboka	220
Bermagui	1160
Wallaga Lake	391
Candelo	352
Cobargo	375
Eden	3280
Merimbula	4270
Tura Beach	1404
Pambula	787
South Pambula	198
Pambula Beach	724
Tathra	1572
Kalaru	211
Quaama	126
Mogareeka	82
Wolumla	269
Wyndham	95
Wonboyn	72
Towamba	73
Urban Areas	**19 841**
Rural Areas	**7 511**
TOTAL	**27 352 ***

* 1996 Total 28 845

2.3 PLANTATION DEVELOPMENT AND MANAGEMENT

Current Commonwealth and State policies, including the RFA's and Plantation 2020 Vision are advocating the expansion of plantations as a land use, for cleared land in both public and private tenure. The issue of where to locate these plantations is one which has forced government agencies to look toward cleared pasture. In relation to water, the revegetation of cleared land has the potential to impact greatly on water quality and quantity.

Variations in canopy cover vary greatly between pasture, plantation and native forest. In respect to water, the canopy cover causes interception of rain which, depending on the species, density and age affects the amount of runoff. Pasture tends to have a constant level of runoff over time (excluding seasonal fluctuations) whereas plantations and native forest produce varied runoff depending on the age and species. Conversion of native forest to plantation can cause streamflow declines due to an increase in interception equivalent to 10 per cent of average annual rainfall. The effect can be important: for an area having an average annual rainfall of 1000mm and a streamflow of 200mm increases in interception would result in a streamflow decline of 50 per cent (O'Shaughnessy, pers.comm).

In addition to designated land use, plantations and native forest may go through varied thinning processes. A plantation with an open spacing would produce more water through lower canopy interception than one with closer spacing. This also varies with species as some species occupy the space produced by thinning operations quicker than others.

Fertilizer application has the potential to impact on water yield and quality. Fertilisers speed up the growth of seedlings, with associated increased water use. Furthermore, fertilisers can have a significant impact on water quality within a catchment. Both pasture and plantations are likely to use fertilisers, although in plantations this is carried out under strict 'Codes of Practice' which enforce buffer zones, filter strips and protection strips to reduce the likelihood of fertilizers entering the stream system.

A review of research material discussed in Cornish (1989a), dealing with the effect of land management on water yield and quality, concluded that the results from comparative studies of hardwood and softwood were not convincing in determining differences in water use other than varying root depths. Studies found that once reaching maturity, different tree species generally consume similar amounts of water. It also found that the construction of roads, logging and clearing of forest for softwood plantation establishment were the main contributors to turbidity (Cornish, 1989). Since these practices were identified, research has been carried out to establish methods which among other things minimise the impacts associated with these public activities. Forest agencies have generally adopted legally binding 'Codes of Practice' which contain prescriptions aimed at the protection of soils and water values. Adherence to the Codes is required for all those engaged in forest planning and production activities. Although various mechanisms can be used to control plantation establishment and harvesting activities on private land there are gaps in the legislative coverage. Codes and legal instrument are being developed to cover these gaps.

A study carried out in the Upper Shoalhaven Valley of New South Wales concluded that the decrease in water yield from land converted from pasture to various forms of forest is not dramatic in extremely dry or wet years. In a 'normal' year, however, the difference is quite marked Costin *et al.*, 1984).

The potential impact of plantations on local and regional streamflows could be modelled using indicative data for the future rate of plantation development. The RFA timetable does not permit this exercise. It is recommended that the exercise be undertaken to look at regional implications as a part of the land use planning process.

2.3.1 Pine

A report by Cornish (1989a) suggests the transformation from cleared pasture to stands of *Pinus radiata* will reduce maximum water yield by 400mm per annum (where annual precipitation exceeds 1300mm). These reductions will vary in part according to annual precipitation in any one year, and the age of each individual stand. The magnitude of water yield decrease with conversion of pasture to plantations will also vary according to the proportional size of the potential plantation in relation to the catchment. Furthermore, the location of plantation adjacent to streamlines may reduce water yield at a local level due to the ready access by trees to soil moisture stored in the riparian zone.

The coincidence of pine plantation establishment and large rainfall events can have implications for land degradation and reduced water quality (Prosser and Soufi, 1997). Whilst future plantation growth will protect the groundsurface from the initiation of erosion, gullies incised during a storm event will continue to develop after plantation establishment in response to processes initiated by throughflow. Within the Eden management area, this could occur in the highly erodible soils developed on granite, such as in parts of the BMA.

2.3.2 Potential eucalypt

Eucalypt plantations in New South Wales are currently being encouraged by the Government particularly on private land as public-private ventures. These ventures are seen as an important step to satisfy demand for potential and existing markets. The demand for plantation timbers is likely to increase due to the continuing reduction in the area available for native forest harvesting. Conservation pressures, Government policy, stabilising degraded land and experimental research improving plantation timber values are all contributing to the potential for timber production from hardwood plantations.

2.4 LOCAL HYDROLOGIC RESPONSES: SEDIMENTATION OF THE LOWER GENOA RIVER

A number of studies have investigated river responses to catchment changes (Cornish, 1989b; Erskine, 1992; McMahon et al, 1992; Warner, 1994; Brooks and Brierley, 1997). In particular, it has been noted that the most vulnerable systems are those located in the granitic landscapes on the south coast of New South Wales (Brooks and Brierley, 1997). This, it has been argued, is in response to the large volumes of highly weathered material which are stored in upland areas, and which are highly sensitive to disturbance. This set of conditions is relevant to concerns raised by stakeholders regarding sedimentation of the lower Genoa River at Mallacoota in response to land cover changes.

Sedimentation of the lower Genoa River is occurring as sand deposits for a distance of >25 kilometres, from Gipsy Point to upstream of Wangarabell. Furthermore, sand deposits are also present in the Victorian reaches of the Wallagaraugh River and accelerated deposition of sandy material in the river delta in Mallacoota Inlet has occurred at a rate of 1 500 $m^3 a^{-1}$ (Erskine, 1992). A report by Erskine (1992) concluded that this process was occurring largely in response to channel erosion of the Genoa River higher in the catchment at Rockton, Wangarabell and Genoa, and of the Nangutta Creek and lower Wangarabell Creek. All of these sites include agricultural land use. Other contributory sources of sediment include native forest clearing for pine plantation establishment in the upper catchment, reconstruction of the Monaro Highway at Rockton and wildfires.

As a sand-bed stream, the Genoa river is particularly responsive to large floods, with channel widening and lowering being followed by gradual recovery (slumping and failure of banks and reworking of the channel bed). Six major flood events have occurred since European settlement, all of which would have been associated with significant sediment mobilisation from hillslopes and drainage channels. The largest flood occurred in 1971, when the peak discharge reached 225 100 Ml/day. Quantitative data for erosion are sparse for this event, but indicative values include (Erskine, 1992):

- 241 000t of material eroded along a 900m reach of the Genoa River at the Jones Creek confluence; and
- 2.13 x 10^6 t floodplain material eroded at Wangarabell upstream of the Genoa River/Big Flat Creek confluence.

Although agricultural land and logged native forests were not considered by Erskine (1992) to be significant contemporary sources, agriculture was recognised as being an important source during past clearing episodes. Clearing for agriculture generally involves removal of virtually 100 per cent of the canopy followed by practices to discourage or prevent regeneration (Brooks and Brierley, 1997). Consequently, in contrast to forest operations when there is an initial increase in discharge followed by a deficit once regeneration commences, the clearing of forest for agriculture modifies the hydrologic regime ‘permanently’. Sediment mobilised during that time would therefore still be held in storage within the stream network (Erskine, 1992). Under these conditions, the impacts of flood events are enhanced.

Accelerated erosion is associated with pine plantation, particularly at the time of planting. One study reported a 3300 per cent increase in sediment yield over ‘natural’ values (Neil and Fogarty, 1991), however, the method of estimation of this value and in particular, the definition of ‘natural’ is unclear. Sediment mobilisation and transport occurs in response to soil surface disturbance at planting and harvesting. However, increased surface runoff from all-weather roads is also a significant source of sediment. Within the Genoa River catchment, hillslope erosion and the supply of large volumes of sand to streams in response to pine plantations have been identified in the vicinity of Bondi Creek and the Upper Genoa River near Rockton (Erskine, 1992). Depositional sites associated with plantations of various ages demonstrate greater sediment delivery rates from plantations established in the early 1970’s than the 1984 plantations. These differences may be a function of distinct management practices including broadscale clearfelling in the 1970’s and the adoption of prescriptions including filter strips and improved road construction and maintenance by the 1980’s. However, the influence of climatic factors may also be contributory. The coincidence of large rainfall events and the establishment of pine plantation can be a significant factor in the initiation of erosion gullying (see Section 2.2.3).

The present limited data suggest that current sedimentation issues are a response to diffuse land cover changes, the 1971 catastrophic flood, and site specific disturbances caused by prior roading and pine plantation activities. Therefore, it can be concluded that sedimentation in the Genoa River is a function of hysteresis, whereby changes in the effect lag behind changes in the cause. However, given the highly erodible nature of soils in the catchment, the concerns raised by stakeholders, and the recommendations by Erskine (1992), further work is required to determine erosion/deposition histories. This would identify channel responses to extrinsic climatic factors and intrinsic (site specific and diffuse) anthropogenic factors within an historical context. The identification of processes and responses could then be used as a predictive tool with applications for management at a catchment scale.

In addition to the sedimentation issues discussed above, community concerns have been raised concerning decreased water quality in Mallacoota Inlet in response to the delivery of nutrient rich suspended sediments. Clay sized particles are highly reactive, so that a significant proportion of available phosphorous can be adsorbed to suspended sediments. There are two sources of nutrients:

- natural phosphorous is associated with the mineral apatite which occurs in volcanic rock such as basalt; and
- anthropogenic nutrients are derived from intensive agricultural and pastoral activities including feedlots, dairies and agricultural fertilizers, and from sewage sludge (Martin and McCulloch, 1995).

Nutrients may be delivered to the stream network from point sources such as sewage treatment works and feedlots, or from diffuse sources, such as the erosion of streambanks and gullies incising phosphorous rich soil material (Olley *et al* . 1996). The soils of the Genoa River catchment are associated with granites of the Bega Batholith. The weathering of granite is not a source of nutrients because of the mineral assemblage of the parent material. Therefore, it is argued here that the nutrients associated with suspended sediments in the Mallacoota Inlet are not naturally occurring, but have an anthropogenic origin. Land use distribution within the catchment suggests that dairies and agricultural fertilizers will be the most likely sources of nutrients, with secondary contributions from urban areas.

The reduction of water quality in Mallacoota Inlet involves two processes: the mobilisation and transport of fine clays and silts; and the sources of nutrients adsorbed to the fines. Whilst the first is a function of soil disturbance within the catchment, the second clearly is not. Therefore, if eutrophication of the Mallacoota Inlet is occurring (and this needs to be clearly established through a monitoring process), the source is unlikely to be forest management practices. However, the tendency for nutrients to sorb very strongly to clayey surface soils emphasises the need for forest management to minimise the delivery of fines to the fluvial system.

2.5 NATIVE FOREST MANAGEMENT

2.5.1 Introduction

The forested catchments of the Eden study area have multiple uses, all of which impact to a greater or lesser degree, on the value of the water resource. Spatial and temporal variation of these activities will impact on the relationship between forest uses and hydrological responses. Furthermore, when water quantity and quality are measurably reduced by such activities, the acceptable limits of those changes will depend partly on the value or end use placed upon the water and aquatic environments.

Land use, surface condition and degree of disturbance are determined by land tenure, which in turn controls appropriate access and management strategies. As discussed earlier, agricultural activities can have major impacts on water quality and quantity . In addition, forest hydrology research has indicated that forest operations may impact on the water resource with implications for public land management issues. In the Eden area, a considerable body of research has been built around *SFNSW, 1994* requirements, which were developed in response to forest harvesting enterprises. This section outlines the impact of other forest activities on the water resource, describes the movement of water through forested catchments, reviews relevant research, discusses the issues of water quality and quantity and examines management strategies which relate to those issues.

2.5.2 Recreation and Tourism

Quality

In comparison with other activities occurring in the EMA, recreation and tourism have a minimal impact on water quality. Streams within the area generally do not lend themselves to recreation activities, particularly those activities which have an impact on water quality e.g. those requiring boats. This is a result of characteristically low water levels during peak tourist season and narrow stream widths which are often overgrown with vegetation (SFNSW, 1994,).

Within the EMA, National Parks have 29 recreation sites which provide tourists with activities such as camping, picnicking, swimming, fishing, bushwalking, canoeing, historic sites, lookouts and some horse riding (Robyn Kesby, NPWS, pers.comm). State Forests in the EMA provide visitors with activities such as bushwalking, swimming, camping, four-wheel driving, fishing, sight-seeing and horse riding (Robyn Kesby, NPWS, pers.comm). The Eden EIS (SFNSW, 1994) also reported motor rallying as a recreational use satisfied by the roading network within State Forests.

The most significant impacts on water quality are caused by four-wheel driving, motor rallying, and horse riding. This is particularly apparent at stream crossings where vehicles and horses mobilise sediments from banks and beds.

Recreation sites within the EMA are designed using management practices least likely to impact on water quality. When designing walking trails, camping and picnic sites, planners take into account minimum distances for buffer strips to reduce the impact on streams.

Additional impacts on water quality are associated with bacterial contamination from tourist camping sites. Moreover, visitors may discharge rubbish and human waste in or near streams which affects water quality with consequent changes to the aquatic habitat. Indirectly, visitors straying off set walking paths in certain areas may lead to further degradation of the soils and ultimately increased sediment loads.

Quantity

Tourism in the EMA has a definite summer peak. With a coastline going from Batemans Bay down to the Victorian boarder a large number of tourist towns are incorporated into the EMA region. Each of these towns receive a huge population boost during the summer months which in turn increases the water requirements.

2.6 WATER USE IN FORESTED CATCHMENTS

Water enters the forested catchments of the Eden study area by rainfall, dew and fog drip and, in the higher elevations to the west, by snow. The water takes a number of pathways:

- a proportion falls directly onto the ground as throughfall;
- some is intercepted by vegetation with a proportion evaporating back to the atmosphere; and
- the remainder flows down branches, trunks and/or stems to the ground surface as stemflow.

At the ground surface water infiltrates the soil until saturation occurs, or the infiltration capacity is exceeded, producing surface runoff (comprising the quickflow component of stream discharge). The infiltration rate is a function of climatic factors including rainfall intensity, and soil factors such as porosity and permeability which are determined by grain size, soil mineralogy and biological activity. Thus, water infiltrates course sandy soils more rapidly than finer textured loams and clays. Yabby burrows, decaying roots and organic matter also result in macropores, high infiltration rates and high hydraulic conductivity. In duplex, or textural contrast soils, water percolating through the soil vertically will be impeded at the boundary of the coarser surface horizons with the finer-grained, less permeable subsoils. Water movement then proceeds laterally along this boundary in a downslope direction as throughflow. This water contributes to the slow flow component of stream discharge. A significant component of water entering the soil, however, recharges the groundwater storage. Groundwater discharge into the stream network along with throughflow provides a steady state flow or baseflow.

Water movement along these surfaces, evaporative and groundwater pathways is impacted by forest in a number of ways. Forest vegetation intercepts and disperses the energy of precipitation, impedes flow and sediment mobilisation/transport and uses available surface and groundwater for nutrient uptake and for efficient gas exchange during photosynthesis. Greater evaporation losses occur from a wetted forest canopy than from shorter vegetation in a comparable environment (Holmes and Wronski, 1982). Significant contrasts in interception losses can exist between forests of different ages, structure and/or species. In particular, interception is an important process for conifers in response to their large leaf area indices (leaf area per unit ground area) and relatively high canopy storage capacities. Changes in streamflow yield can be associated with conversion of forest type (eucalypt → conifer) as a function of these different canopy interception rates. (Dunin and Mackay, 1982). Interception differences between pine and eucalypt also account for variations in runoff for paired catchments (Pilgrim *et al.*, 1982). Similarly, physiological differences between young-medium age forests and old growth forests can be reflected in changing interception and evaporation losses as a forest ages. Furthermore, the active, deep root zones of trees create large soil water deficits during dry periods, which require greater recharge before significant surface runoff occurs (Moran, 1988).

Catchment water yield will increase significantly after forest removal due to timber harvesting and/or wildfire as a result of lower infiltration rates, as a function of fire induced hydrophobicity, lower evapotranspiration and reduced interception. Yields then return slowly to pre-logging treatment/fire conditions in response to revegetation and canopy recovery (Dargavel *et al* ., 1995).

2.7 CATCHMENT HYDROLOGY RESEARCH IN THE EDEN RFA REGION

Water quality and quantity coming from the catchments within the Eden RFA area are issues which have been studied for many years. Research has been conducted by a range of interested parties including State Forests of NSW, Cooperative Research Centre for Catchment Hydrology, CSIRO, DLWC and Local Governments.

With the varied uses and forest types within the EMA these studies have covered a wide variety of issues and variables which can contribute to quality or quantity. Most of the studies have been carried out on a catchment basis. The varying catchment characteristics, such as slope, soil type, climate, forest age and structure influence the response to catchment treatment and subsequent changes in water yield and quality.

Yambulla Catchment

The majority of papers below are reviewed by Harper and Lacey (1997).

- integrated harvesting for sawlogs and woodchips on soil erosion, water quality and water yield (Mackay, 1989) and complementary forest hydrological process studies by the CSIRO (Cropper *et al*., 1989 and Moore *et al* . 1986)
- water quality parameters, suspended sediment analyses and reporting (Olive and Rieger, 1987)
- comparison of water quality trends between Tantawangalo and Yambulla catchments (Williams, R.D and Mackay, S.M, 1988)
- description of soils and soil landscapes (Ryan, 1993)
- the effect of logging combined with wildfire on storm peaks and baseflow increases (Mackay and Cornish, 1982)
- the effect of logging without wildfire on runoff (Cornish, 1991)
- the effect of soil compaction on hydraulic conductivity of the soil (Moore *et al* ., 1986)
- likelihood of overflow on compacted areas of harvesting coupes such as tracks and the reliability of buffer strips to stop sediment moving into streams (Bennett, 1988)
- the suspended sediment concentrations being low and dominated by storms (Olive and Rieger, 1987
- increasing turbidity levels in streams in the year of logging and declining as vegetation returns to the site (Cornish and Binns, 1987)
- variation of dissolved ion concentration with stream discharge (Cornish , 1982)
- increase of wildfire leads to an increase in potassium and nitrate concentrations in the year following (Mackay and Robinson, 1987)
- initial concentrations of cations decrease in logged and burnt catchments after which they increased to levels higher than before the wildfire occurred (Cornish, 1987)

Tantawangalo Catchment

- quantitative description of the vegetation within the Tantawangalo Research Catchment boundaries (Dodson, J.R, Kodela, P.G and Myers, C.A, 1988)

- the effects of logging on water values using water quality sampling and analysis (Cornish, 1992)
- investigation of possible water yield changes after logging (Cornish, 1991)
- the effects of logging on water yield (Ed Wronski and Associates, 1993)
- comparison of water quality trends between Tantawangalo and Yambulla catchments (Williams, R.D and Mackay, S.M, 1988)
- description of the vegetation found within the catchment (Dodson *et al* ., 1988)
- description of the geology and soils (Ryan *et al* ., 1989)

Note: although most of the research for the studies in Tantawangalo have been done by State Forests a Tantawangalo Technical Committee provides guidance in the form of expertise from the CSIRO, Melbourne Water, DLWC, Local Government and State Forests members.

Wallagaraugh Catchment

- streamwater quality following logging and wildfire (Cornish, P.M and Binns, D. 1987)

Towamba Catchment

- streamwater quality following logging and wildfire (Cornish, P.M and Binns, D. 1987)
- forest management strategies for the monitoring of water quality specific to Towamba Valley (Turner *et al* ., 1996)
- assumptions and scenarios for sustainable forest management using different management techniques (State Forests of NSW, 1996)

Bemboka Catchment

- study of the relationship between land use and water resource availability in the catchment (Gutteridge Haskins and Davey Pty Ltd, 1997)

Other research projects over the catchments

- the effects of radiata pine plantation establishment and management on water yields and water quality (Cornish, 1989)

In addition to the forest harvesting activities which effect water quality coming off areas within the catchments, roading is a practice which can greatly affect water quality. It has become apparent that forest road management practices and the implementation of these practices have an important role in reducing impacts to the water systems within the catchments. These practices are aimed at reducing the impacts from not only harvesting but also roading. Recreational activities within forested areas, such as 4-wheel-driving and rally car racing, also have major impacts on the quality of water.

2.8 EFFECTS OF FOREST MANAGEMENT AND WILDFIRE ON WATER QUANTITY

Catchment water yields normally respond to changes in forest density and age caused by wildfire, forest harvesting and forest clearing. A decrease in water yield has the *potential* to: adversely affect aquatic ecosystems; produce conflicts between users downstream; and/or, necessitate further development of water storage capacity/groundwater resource to maintain adequate supply.

Hydrologic trends in response to forest age have been determined for ash-type forests in Victoria. Following wildfire or harvesting there is an initial increase in streamflow. After 7-10 years streamflows decline in response to increasing water requirements of regrowth, with a minimum streamflow value occurring approximately 27 years after fire (or clearfelling). As the regrowth matures, catchment water yield will gradually increase to pre-treatment levels after 100-150 years (Langford, 1976, Kuczera, 1985). However, these responses are specific to ash-type forests. The effects of forest harvesting and wildfire on mixed species forests are more complex and uncertain.

- Studies in the Otway Ranges, Victoria, indicate that yields in mixed species forests vary according to location (controlled by elevation, soil type and depth, and aspect), vigour of stands and possibly forest age (Moran, 1988). Negligible changes in yield with age occur in the drier forests with changes similar to low rainfall ash forests in the wetter areas.

- Mixed species forests are capable of recovering from low to medium intensity fire, so that after any fire event there may only be limited areas of regrowth forest created (Kuczera, 1985). In these forests, which occur throughout the Eden forest region, fire may not have as significant an effect on the water yield as in ash type forests. However, where both logging and wildfire have occurred in moist sclerophyll forest, hydrologic responses have included increases in baseflow and marked increases in peak flow response (Mackay and Cornish, 1982). Total runoff returned to pre-fire levels within four years, or within eight years in the case where logging and fire occurred in combination (Mackay, 1988). However, residual effects remained in the most intensely disturbed catchments of dry sclerophyll forest (Harper and Lacey, 1997).

  Care has to be taken in extrapolating the results of the ash type forests of the Melbourne catchments to the Eden mixed species forests. The Eden soils are generally more shallow, the rainfall more irregular and forest response to wildfire in particular, more variable.

  Elucidation of the effects of forest change on water yield in the Eden mixed species forests awaits analysis and publication of the results of 10 years of monitoring for both the Tantawangalo and Yambulla experimental catchments plus the analysis of existing streamflow records such as those available for Rutherfords Creek, a tributary of the Bemboka River (O'Shaughnessy, pers.comm.).

  Currently the Co-operative Research Centre for Catchment Hydrology is also undertaking extensive process studies in the mixed species forests and are examining the relationship between stand density, leaf area and sap flow.

- In high rainfall mixed species forests at Karuah, north eastern New South Wales, water yields increased in the first year after clearing, with decreases occurring about two years after logging in response to abundant regeneration (Cornish, 1993). Further decline in the following four years, to a value significantly lower than pre treatment levels, was related to the mean stocking rate of the eucalypt regeneration. However, in a catchment where the effective area of vegetation reduction was <20 per cent of the total catchment area, no initial increase of catchment yield occurred. These results are verified by work in moist eucalypt forests at Tantawangalo forest, where total streamflow remained at or above pre-logging levels four years after logging (Cornish, 1994). Disaggregation of the results shows that quickflow dominated the initial increases, but this rapidly declined over the following three years in response to surface cover regeneration, when baseflow became predominant (Cornish, 1994). Studies in the dry sclerophyll forest of the Geebung catchment partitioned total runoff into quickflow and baseflow using a low frequency pass digital filter. This study indicated that post logging baseflow is significantly greater than pre logging baseflow (Crapper *et al.*, 1989). However, the length of study period (2 years) precludes an analysis of the persistence of this effect over time.

- Surface runoff volumes are influenced by soil physical characteristics, including fabric, depth, texture, hydraulic conductivity and infiltration capacity. Changes to soil structure and vegetation cover in response to disturbance by logging are further contributory factors. Whilst clear relationships have not been determined between soil type and runoff production, the degree of soil disturbance is significant with greatest measured runoff volumes on compacted snig track surfaces. These responses are a function of decreased hydraulic conductivity due to destruction of soil macropores by vehicular traffic (Moore *et al*, 1986). Comparative measured values of runoff for snig tracks and the general harvest area indicate that seven times more surface runoff per unit contributing area is generated on snig tracks on recently logged sites (Croke *et al.*, 1997). The relative difference in runoff yields declines over time and with increasing vegetation cover.

- Research in mixed species forest in the Eden forest region provides variable results for yield reduction in comparison with pre-treatment levels. Harper and Lacey (1997) suggest, for the Yambulla catchments, that although all runoff parameters initially increase in response to logging and wildfire, there is no evidence to suggest that total yield is ultimately reduced to below pre-treatment levels. This is in contrast to very early results derived by Wronski (1993) for the wetter Tantawangalo mixed species forest, and summarised by O'Shaughnessy and Jayasuriya (1987), for the Ash type forests. These variable results emphasise the need for more research and analyses of existing data for the Eden catchments.

Impacts of proposed forest management activities on water yield will vary in response to local site conditions, including catchment area, percentage forest cover, roading infrastructure harvesting operations and frequency of prescribed burning (*SFNSW, 1994,*). Predictions of initial increases in catchment yields from harvesting operations in 'representative' catchments have been determined for the Eden region (Table 13). These predictions are based on assumptions relating to percentage reduction of crown cover. A rate of 40mm/yr change in yield per 10 per cent cover reduction (Bosch and Hewlett, 1982) represent an upper limit. Dargavel *et al*., (1995) quote Nandakumar and Mein as estimating a peak increase of 330mm following total clearfelling. Furthermore, the estimates assume a ten-year return to pre-treatment levels following forest harvesting. It is assumed there are no yield declines. The data, as presented, are therefore indicative rather than definitive, and represent outcomes based on harvesting all available compartments in each catchment at the one time. Furthermore, the data do not reflect longer term spatio-temporal changes in catchment responses. However, despite these limitations and the inherent assumptions, it should be noted that the maximum available net logging area (Allan Brook @ Allan Brook Road (Yambulla SF) at 24.9 per cent of the total catchment results in a 6 per cent increase in mean annual water yield (SFNSW, 1994) over the period of the EIS (3 years)

TABLE 13 PREDICTED MAXIMUM CHANGES IN RUNOFF FROM FOREST OPERATIONS IN 'REPRESENTATIVE CATCHMENTS' IN THE EDEN REGION FOR A THREE YEAR PERIOD ONLY.

Catchment	Area (ha)	Avail. net logging area (ha)	Avail. net logging area (% of catchment	Avail. net logging rate (ha/yr)	Max. increase in mean annual water yield (mm/yr)
Allan Brook @ Allan Brook Rd (Yambulla SF)	7412	1850	24.9	616	16.6
Imlay Ck @ Wallagaraugh R. confluence (Yambulla, East Boyd, Timbillica SFs)	9190	610	6.6	203	4.4
Wallagaraugh R @ Princes H'way (Yambulla, East Boyd, Timbillica SFs)	48 204	4300	8.9	1433	5.7
Rutherfords Ck (Glenbog SF)	2134	208	9.7	70	6.6
Cuttagee Ck (Murrah SF)	3700	482	13.0	160	8.3
Stockyard Ck @ Rocky Hall (Coolangubra SF)	7948	378	4.7	126	4.5

(After SFNSW, 1994)

Research in Melbourne Water catchments has involved comparative studies of the impacts of various treatments on catchment hydrology. These treatments include:

- Thinning - a 54 per cent patch cut and a 50 per cent uniform thinning increased streamflows by about 20 per cent over 12 years, with the 50 per cent thinning being more persistent. The thinned forest maintained its annual growth rate because the remaining trees grew faster (O'Shaughnessy and Jayasuriya 1991).

- Clear felling and regeneration at densities of 500, 2 000 and 20 000 trees per hectare. Monitoring of the effects on streamflow is continuing, but a longer data run is required before conclusions can be drawn (O'Shaughnessy and Jayasuriya 1991). However, it has been demonstrated in one study (Grayson *et al.* 1993) that harvesting and regeneration does not have a major impact on water quality in the absence of stream crossings. The research also showed that adherence to the prescriptions of no logging in wet weather, the use of buffer strips, and the proper management of runoff from roads, snig tracks and log landing areas prevented the entry of contaminated runoff into streams.

- Strip thinning - alternate 35 m wide strips cut along the contour have increased streamflow by 20 - 25 per cent (O'Shaughnessy and Jayasuriya 1991, O'Shaughnessy *et al.* 1993). Overall reduction in annual growth rate by ~40 per cent has occurred because growth response to thinning has been restricted to the boundaries of the retained strips (O'Shaughnessy and Jayasuriya 1991).

2.9 EFFECTS OF FOREST MANAGEMENT AND WILDFIRE ON WATER QUALITY

Suspended sediment

Water quality of streams draining harvested forest areas can be affected by the delivery of sediments from disturbed land surfaces as surface runoff detaches and mobilises soil particles. These sediments may be transported a relatively short distance and re-deposited on the surface downslope, or may enter streams. The detachment and transport of sediments is a function of soil physical and chemical characteristics, surface condition, slope and climate. Log landings and snig tracks, which may cover up to 25 per cent of the logging coupe (Rab, 1992), can produce the greatest proportion of runoff as a result of compaction and the development of preferential pathways for convergent flow. Measurement of sediment movement in forested catchments of the Eden region indicate that runoff and sediment yield are highest on compacted snig tracks *across all soil and forest age categories* (Croke *et al.*, 1997). Generally, snig tracks generate 7 times more surface runoff and 20 times more sediment per unit area than the general harvesting area (*ibid*). Furthermore, the general harvest area is a mass depositional site, largely as a function of material originating from the snig tracks being redeposited on the perimeters of the GHA (Roddy, 1997).

In addition to the results from these studies, research into sediment production levels from unsealed forest roads suggests a positive relationship between the frequency of road use and the production of *coarse* sediment and total sediment. This confirms the need for high standards of road construction and management to help prevent the entry of runoff into streams (Haydon *et al.* 1991).

Whilst coupes usually cease acting as sediment sources some five years after forest harvesting due to the development of litter and plant cover on disturbed areas such as snig tracks, roads which remain open can act as permanent sediment sources. Here, the level of sediment production will vary according to the levels of road use and maintenance. Smith and O'Shaughnessy (1997) state that due to channelization, flows from drainage outlets travel on average 25m whilst 20 per cent of sediment flow travels > 40m. Therefore, special precautions and buffer widths are needed where roads are located parallel to streams and at stream crossings.

Problems with roads and water quality will vary according to whether alternative silvicultural systems, thinning systems, or clear felling systems, are practiced. For example, according to O'Shaughnessy and Jayasuriya (1987), in clearfelling operations much of the road network can be closed and revegetated until the next rotation harvest time. Older harvesting systems clearfelled large areas in a short time period thus allowing many secondary roads to be taken out of service. In contrast, alternative silvicultural systems might require more regular access and hence the need to maintain the road network. Furthermore, where dispersed harvesting systems are used to protect fauna (as in the EMA), more roads have to be kept open. The potential issue here is that it has been found that it is the road network, rather than the forest harvesting operations, which has most potential to create water quality problems in forested catchments.

In reviewing the impacts of timber harvesting on water quality, Dargavel *et al.* (1995) highlighted the importance of the standard of forest management practices and their application, which in turn depends on the level of resourcing and training of field staff, and the need to upgrade much of the old roading infrastructure. They also concluded that avoidance of direct stream disturbance by these activities and prevention of turbid inflows will provide a high level of protection. Further, the recreational use of forests, particularly four-wheel-drives, may contribute to erosion and reductions in water quality. O'Shaughnessy (1995) also stressed the importance of compliance with timber harvesting codes of practice for maintaining water quality, particularly in applying such codes to road construction and maintenance.

These conclusions are verified by estimates of annual sediment production from roading infrastructure in the Eden region which demonstrate the variability of values in response to road class and site conditions (Table 14). These data assume an annual fine sediment production rate of 20 t/ha/yr based in part on the Melbourne Water Road 11 experiment results (O'Shaughnessy and Jayasuriya, 1987). The data were derived from monitoring silt production from an unsurfaced fire access road subject to varying levels of maintenance and use. Maximum use was only 30 light 4WD trips per week. However, total sediment production including bedload and suspended material varied from 50-90t of sediment per ha of road per year. Thus the sediment production rates in Table 14 are very conservative. The Road 11 rates highlight the need to have high levels of stream protection at roading design, construction and maintenance stages.

TABLE 14 ESTIMATES OF ANNUAL SEDIMENT PRODUCTION FROM ROADS IN THE EDEN MANAGEMENT AREA

Proposed new roads	Road statistics			Sediment production (t/yr)		
	Length (km)	Width (km)	Total area (ha)	Coarse >125µm	Fine <125µm	Total
Class III roads						
Big Jack Rd (Coolangubra)	5.3	4.2	2.23	31.2	13.4	44.6
Jill Road (Cathcart)	0.7	4.2	0.29	4.1	1.7	5.8
Bredbendoura Road (Cathcart)	1.2	4.2	0.50	7.0	3.0	10.0
Trapyard Creek Rd (Murrabine)	3.3	4.2	1.39	19.5	8.3	27.8
Totals	**10.5**		**4.4.1**	**61.8**	**26.4**	**88.2**
LSA minor access roads						
LSA red zone compartments	40.5	3.0	12.15	56.7	24.3	81.0
LSA yellow zone	51.0	3.0	15.30	71.4	30.6	102.0
LSA green zone	36.0	3.0	10.80	50.4	21.6	72.0
Totals	**127.5**		**38.25**	**178.5**	**76.5**	**255.0**

After *SFNSW, 1994*

Current research in the Eden Management Area has shown that on-site erosion rates and sediment yields *on snig tracks* are highest on granitic soils and relatively low on soils associated with Ordovician metasediments (Croke *et al.*, 1997). This may be due to the relative ease with which sand sized particles in a highly dispersible clay/iron oxide matrix can be detached by rainsplash and surface flow processes in granitic soils. In contrast, the export of material from plots was greatest in the finer grained soils derived from the Ordovician metasediments. Early conclusions from this work suggest that the clays in these soils can remain suspended for longer periods, and hence distances, than the coarser fractions of the granitic soils. Consequently, the soils associated with the Ordovician metasediments may “pose a greater threat to in-stream water quality” than the coarse granitic soils. However, to increase the confidence of these statements, more research is needed to compare the behaviour and responses of the clay sized fractions of these different soils. Differences in sediment delivery to streams in the Tantawangalo Research Catchments have been ascribed to clay content in surface soils developed on Bemboka Granodiorite (Cornish, 1992).

The transport of suspended sediment is a function of discharge, flow velocity, particle size and surface roughness. Research indicates that whilst a significant volume of soil material may be detached and transported over short distances, most of it is redeposited within the catchment (Mackay *et al.*, 1985). Furthermore, soil stability will increase with time after logging and/or fire, as revegetation occurs, with minimal soil movement occurring after five to nine years (Mackay, 1988). The most significant changes to suspended sediment loads have been recorded in logged and burnt catchments, where surface runoff increases, and surface roughness decreases in response to loss of vegetation and organic soil material. Increases in suspended sediment concentrations range from 20-160 per cent in the Tantawangalo Research Catchments (Cornish, 1992) with extreme values as high as 800-1000 per cent recorded in Yambulla (Olive and Rieger, 1987; Harper and Lacey, 1997). Higher turbidity levels occur during years when logging has occurred, particularly during wetter years (Cornish and Binns, 1987). Moreover, differences in turbidity levels at a catchment scale have been attributed to the proportion of a given catchment logged (*ibid*). Wildfire alone does not have a significant effect on turbidity levels: pre-fire alternate coupe logging of 36 per cent of one subcatchment and post-fire clearfall logging of 86 per cent of another subcatchment yielded similar changes in turbidity (Cornish and Binns, 1987).

Comparisons of hydrological responses in treated and untreated catchments, particularly relating to sediment load, need to be made within the context of the highly variable flow and storm response patterns of the streams in the region (Olive and Rieger, 1987). Measured suspended sediment loads in the streams are low (0-160mg L^{-1}) and are storm dominated, with quick response rates by streams being reflected in short duration, high storm-related concentrations (Olive and Rieger, 1987; Williams and Mackay, 1988). Nevertheless, responses can be complex and variable (Harper and Lacey, 1997). Furthermore, where measured sediment loads are storm related, sediment depletion or exhaustion in multiple events suggests that sediment supply is finite in undisturbed catchments (Olive and Rieger, 1987). The limiting factor on supply is possibly caused by reduction of fine particle detachability after soil wetting. This would contribute to sediment depletion in conditions where a major proportion of excess rainfall reaches drainage lines as quick response, shallow throughflow as suggested by Moore *et al*.,1986b.

Solutes

Catchment lithology and distance from the coast define specific geochemical signatures of streams and water bodies in the area. However, within these constraints, detectable changes have been detected in ionic concentrations in catchments which have been logged and/or burnt. However, the results from several studies indicate that responses are complex and localised. A study in the Wallagaraugh catchment demonstrated that exports increased significantly after fire, and by 200-700 per cent for the following three years, in an unlogged catchment (Mackay and Robinson, 1987). Higher rates of runoff were associated with the increased exports. Comparison of burnt catchments with a burnt, partially logged (36 per cent) catchment did not produce large scale differences in stream chemistry (*ibid.*). By contrast, ionic concentrations decreased in small-subcatchments in the Wallagaraugh and Towamba catchments following logging/fire, becoming relatively greater than pre-treatment conditions 3-4 years later (Cornish and Binns, 1987). Small scale hydrologic changes in subcatchments affected by drought and logging/fire may have influenced ionic release and ionic transport processes at a local scale. Whilst variations in solute concentration were detectable at a local scale, they were buffered out in the major rivers of the catchments (Cornish and Binns, 1987).

Bedload

Limited work has been undertaken on changes in sediment delivery and transport as bedload. Where increases have been detected, these have been attributed to streambank collapse in response to higher flows after logging and/or wildfire (Crapper *et al.*, 1989; Olley *et al.*, 1996; Harper and Lacey, 1997). If this is the case, then accelerated streambank erosion may be an off-site impact of logging/wildfire. In addition to these losses of soil at a local level, increased bedload may have impacts on macroinvertebrate habitats. However, analyses indicate that bedload accessions are low (Harper and Lacey, 1997).

3. MANAGEMENT OF CATCHMENT AND WATER VALUES

The implementation of ecologically sustainable forest management (ESFM) through the RFA process is based on the components of an environmental management system (EMS):

1. Commitment and policy framework
2. Planning
3. Implementation
4. Forest Information and monitoring
5. Review and improvement

An environmental management system is an approach to planning and operations based on quality management systems developed for industrial processes. Environmental management system involves the transparent process of goal or target setting, based on the policy and legislative requirements, planning and implementation in accordance with goal setting, and monitoring and evaluation of outcomes against performance targets. It is a holistic approach to management, allowing for the incorporation of risk-management in decision-making and implementation, using best-available knowledge. Fundamental to the process is a commitment to continuous improvement, based on monitoring and evaluation.

An assessment of ecologically sustainable forest management at the RFA and State-wide level has been made and the following should be read in conjunction with the ESFM report, as it contains detail relating to the EMS components, that has contributed to the assessment of ESFM. It is also presented in order to provide the reader with an understanding of management arrangements and processes concerning catchment and hydrology values in the Eden region

3.1 COMMONWEALTH POLICIES AND INITIATIVES

Under the Australian constitution, the main responsibility for water resource planning and management lies with the State and Territory Governments. The Commonwealth Government has a complementary role in natural resource management. This relationship is best demonstrated in the Council of Australian Governments (COAG) Water Reform Framework.

3.1.1 COAG water reform framework

In 1994, COAG agreed to a strategic framework for water reform in Australia. The framework has a key role in improving the sustainability of natural resource use, achieving better environmental outcomes and contributing to the overall micro-economic reform agenda. In the case of rural water services, the framework is intended to generate the funds to maintain supply systems and through a system of tradable entitlements to allow water to be used for higher value uses subject to social, physical and environmental constraints.

The key elements of the framework are:

- pricing reform
- clarification of property rights
- allocation of water to the environment
- adoption of trading arrangements in water
- institutional reform, and

- public consultation and participation.

Also included under the framework is the adoption of an integrated catchment management approach to water resource management.

It is intended that the State and Territory Governments will have implemented the framework by 2001 with property rights in place (including environmental allocations) and water trading occurring no later than 1998. Implementation will be progressively measured by determining whether or not milestones (still being determined) have been met by the States. The implementation of the framework is linked to payments to State and Territory Governments by the Commonwealth Government that will be made available under the Competition Principles Agreement (COAG, 1994).

Each State and Territory is currently in the process of developing approaches to implementing the framework. This has been assisted by the work of the Agriculture and Resource Management Council of Australia (ARMCANZ) and the Australian and New Zealand Environment and Conservation Council (ANZECC). ARMCANZ developed a paper entitled Water Allocations and Entitlements - A National Framework for the Implementation of Property Rights in Water (1995) and ARMCANZ and ANZECC developed the National Principles for the Provision of Water for Ecosystems (1996).

3.1.2 National Water Quality Management Strategy (NWQMS)

The NWQMS has been developed since 1992 and consists of a number of separate documents that outline national approaches and guidelines for different water qualities. The objective of the NWQMS is to achieve sustainable use of the nation's water resources by protecting and enhancing their quality while maintaining economic and social development. The NWQMS provides a nationally consistent approach to water quality management through the co-operative development of guidelines. The guidelines promote a shared national objective while allowing flexibility to respond to regional and local differences.

One of the guiding principles of the Strategy is the adoption of an integrated approach to water quality management. Such an integrated approach to resource management includes:

- a holistic approach to natural resource management within catchments, marine waters and aquifers with water quality considered in relation to land use and other natural resources
- co-ordination of all the agencies, levels of government and interest groups within the catchment
- community consultation and participation (NWQMS Draft Implementation Guidelines 1995).

As part of the NWQMS, guidelines have been developed for Fresh and Marine Waters which collate available scientific information to recommend water quality guidelines for aquatic ecosystems; drinking water; recreational water; industrial and agricultural water (NWQMS Australian Water Quality Guidelines for Fresh and Marine Waters 1992).

3.1.3 National River Health Program (NRHP)

The objective of the NRHP is to improve the management of Australia's river systems through improved information bases on the state of rivers (Managing Australia's Inland Waterways 1996). The NRHP was primarily established to implement the Monitoring River Health Initiative that aims to develop a national approach to river health monitoring. Another major component of the NRHP is developing means of assessing the water requirements that are necessary to maintain a healthy functioning river ecosystem(NRHP Leaflet 1993). A number of sites in the Eden area have been included in the national program to establish baseline data for the NRHP (Cornish, pers.comm.).

3.1.4 National Rivercare Initiative

The proposed National Rivercare Initiative will build on existing programs to help ensure the sustainable management, rehabilitation and conservation of rivers outside the Murray-Darling Basin. It is intended that the initiative will provide financial assistance for catchment management planning and implementation. Local communities will be encouraged to develop catchment and sub-catchment management plans to ensure water resources are managed sustainably according to local goals that are consistent with NWQMS guidelines (Managing Australia’s Inland Waters 1996).

3.2 STATE POLICIES LEGISLATION AND INITIATIVES

New South Wales has a number of Acts and policies for stream, soil and environmental protection. Many were developed in response to historical circumstances and date back to the 1920's and 1930's. Some of the legislation provides severe penalties for breaches of the Act. many of these penalties have never been invoked giving rise to concerns as to whether they could now be applied. Again, much of the legislation is only invoked in response to a permit application. There is a high potential for poor practice to continue due to a lack of supervisory processes and the political reluctance to confront private land owners. The current status of New South Wales legislation has been reviewed in a CSIRO Assessment Report on New South Wales Codes of Plantation Practice prepared by CSIRO Forests and Forest Products. The Timber Plantation Harvest Guarantee Act 1997 allows for timber harvesting of plantations subject to a code of practice. Consequently, codes will be developed for private land dealing with clearing for plantations, plantation establishment, and plantation harvesting. Furthermore, existing legislation is being reviewed in terms of potential consolidation and simplification (Peter Moore, DLWC, pers.comm.).

New South Wales State Government Policy, as reflected in recent initiatives and legislation, emphasises that land and water are inseparable and, consequently, the State Government has directed public authorities to aim for stable, well managed systems which will protect and not damage rivers and their environments. State Government policy to protect water quality is implemented through a raft of policy and legislative mechanisms, some of which are listed below:

- Clean Waters Act, 1970
- Pollution Control Act, 1970
- Protection of the Environment Administration Act, 1991
- Soil Conservation Act, 1931
- Environmental Planning and Assessment Act, 1979
- Environmental Planning and Assessment Regulation, 1994
- Environmental Offences and Penalties Act, 1989

3.2.1 Pollution Control Licence

A Pollution Control Licence, in respect of Section 17A(b) of the Pollution Control Act 1970, was granted to the State Forests of New South Wales on 8 August 1996 for a period of one year and renewed in August 1997. This licence contains 145 conditions and is very detailed in terms of requirements and reporting. Schedule 4 converts many of the "shoulds" in the standard Erosion Mitigation Guidelines into imperatives. The principal goal of this licence is to protect the aquatic environment from pollution caused by logging operations. A further requirement of the licence is to monitor the effectiveness of the licence conditions in achieving the relevant environmental goals.

The licence provides a set of legally enforceable requirements and guidelines for use by forest managers to protect and manage water values or uses. Schedules within this document prescribe:

- Information to be contained within a harvesting plan or roading plan;

- methods for assigning water pollution hazard categories and determining the proportion of dispersible soils;
- Water pollution hazard conditions for use with harvesting plans, roading plans and burning plans; and
- A water quality monitoring program in a network of representative catchments.

3.2.2 The Forest Practices Code

The Forest Practices Code for Timber Harvesting in Native Forests is a document which sets out minimum codes of practice for timber harvesting operations in New South Wales. The Code is based on two documents: “Forest Practices related to Wood Production in Native Forest: National Principles” by the Standing Committee of the Australian Forestry Council in May 1991 and “The National Forest Policy Statement” ratified by the Commonwealth and States (excluding Tasmania) in November 1992. A review of aspects of the Code has since been undertaken (CSIRO, 1997)

The Code sets down a framework of standards that apply to timber harvesting at all scales, from the Forest Management Area to the coupe level. The Code contains a number of provisions to minimise soil erosion and protect water quality in forest areas. Furthermore, it provides the basis for detailed harvesting prescriptions, taking into account local conditions such as slope, soil type, rainfall and the type of harvesting operations. *Minimum* standards are provided as guidelines, but these may be increased to optimise environmental protection through local prescriptions in coupe plans.

There is currently lively debate current in Australia between regulators and land managers as to the degree to which Codes should be output based rather than prescriptive. Whilst an output based system would be preferable in the long term, at this stage in the development of land use regulatory systems, certain basic requirements have to be set. It is considered that better monitoring systems with feedback into practice are required before totally output based systems can be used.

The Pollution Control Licence and the Forest Practices Code deal with issues relating to water quality. Impacts of forest practices on water yield are not covered, except indirectly through surface runoff/roading relationships.

Both documents contain guidelines and prescriptions which are based on assumptions, including:

- Prescribed minimum widths of filter strips assume that site conditions support vegetation. In some locations, drainage features will incise rock outcrops or saprolite which can not support vegetation. Where this occurs, the minimum filter strip width would be inadequate to retard sediment movement.
- Soil erodibility is defined in terms of clay dispersion characteristics. Given that a significant proportion of the Eden region is associated with granitic parent material, where soils may be thixotropic (refer to Section 2.1.6), this approach has limitations.

3.2.3 New South Wales Water Reforms

Introduction

In 1995 the NSW government started a major reform process as a step towards sustainability of water use. These reforms include:

- the introduction of a water management charge for most water users
- referral of bulk rural water pricing to the Independent Pricing and Regulatory Tribunal
- delivering water to two significant natural areas of the state, the Macquarie Marshes and the Gwydir wetlands,
- introducing a Healthy Rivers Commission to look at priority rivers in need of attention.
- the development of interim water quality and river flow objectives for the State’s rivers.
- the establishment of a Water Advisory Council which comprises community representatives to advise on the implementation of the reforms.
- changes to the Fisheries Act.

1997 Water Reform Proposals

Further proposals are set for release by the NSW Government which advance on previous strategies, but also respond to community pressure. Two outcomes from this process will include resource security to water users and a share of water to the environment. Additional initiatives included in the package are a State weir policy, a State groundwater policy, an approach for identifying and acting upon rivers identified as stressed, and a water access and use rights discussion paper.

Sharing water on Regulated rivers

The government has announced that, on regulated rivers, which would include the Brogo and Bemboka Rivers, regulated by the Brogo and Cochrane Dams respectively:

- water users will receive a share of water guaranteed for a fixed term of five years from 1997/98 to 2002/03.
- the environment will receive a share of water for the next five years that is based on rules which have been set for the first year (1997/98) by the government.
- river flow committees will be set up within the community to monitor the rules, assess their impact and make recommendations on adjustments for years 2 to 5. Any changes to the rules cannot deliver a share to the environment that is greater than the upper bound determined by the government.
- if at any time during the five years, agreement can be reached between the committee and government on longer term objectives, then a longer term resource secure period could be set for water users.

Unregulated coastal and inland rivers.

By January 1998 coastal streams and unregulated inland rivers will be classified into:

unstressed;

stressed; and

high conservation value.

The stressed rivers classification will form the basis for prioritising action and for the Healthy Rivers Commission inquiries. The DLWC will coordinate the preparation of water management plans for the stressed rivers and plans will be developed by working groups by the year 2000.

Environmental Objectives

Draft water quality and river flow objectives for the State’s rivers are currently being developed and will be used to formulate catchment water quality management plans. These plans will be produced under the auspices of TCM committees’ catchment management plans or strategies.

State Groundwater Policy

An initial classification of aquifers is currently being undertaken by the DLWC which includes: low, medium and high risk categories, based on an assessment of potential or actual over-extraction and pollution. This approach forms the basis for prioritising management plans, which are being developed by stakeholder working groups.

State Weir Policy

This policy establishes principles for considering new weir proposals or proposals for extending existing weirs and may include an audit of the presence, function and operation of all weirs by the DLWC.

Water Access and Use

Water users have been seeking greater certainty about their rights to access and use water. A discussion paper has been prepared which sets out existing water rights, outlines the current reform proposals and poses a number of issues that need to be considered in developing an access rights system. The paper is being released for community discussion.

4. CONCLUSION

Potential impacts of forest management on catchment hydrology include dynamic changes to water quality and yield. Results derived from studies in a range of catchments, with diverse physical characteristics, suggest that these impacts vary temporally and spatially and are dependent on a number of extrinsic and intrinsic variables. In catchments with a range of land uses and management strategies, it is difficult to isolate relationships between specific land use practices and hydrological responses. This is particularly the case in catchments where both agriculture and forest management occur. However, research has identified and quantified potential and/or actual changes in water yield and quality in relation to forest practices. The evidence suggests the magnitude of these changes are proportional to the area logged and are responsive to conservative management strategies. Furthermore, whilst impacts may be expressed at a local or subcatchment scale, they may be buffered out a catchment scale.

It should be noted that management practices in place for the protection of water values are dynamic, and are subject to review and development. However, it needs to be stressed that effective management of water in forested catchments is reliant on the observance of forest codes of practices and local prescriptions, with the support of sound scientific monitoring, analysis and assessment.

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5.1 APPENDIX 1

Protection of Native Vegetation on Private Land (Prepared by P. O'Shaughnessy after interviews with local staff, 1997)

Bega Valley Shire has a tree preservation order which effectively only applies to urban areas. There is a thrust to regional Vegetation Plans under the Soil Conservation Act replacing SEPP 46 regulations. State Environment Planning Policy No. 46 is aimed at preventing inappropriate native vegetation clearance in New South Wales. The administration of SEPP 46 is still an issue in the RFA as, for example, Harris Daishowa want to clear native vegetation on private land for plantation development. The officers felt that the RFA area contains areas which have regenerated over the past 50 years which often supports vegetation that land owners want to clear. There is also a constant demand to clear and pulp forests and remnant woodland.

The regulations for SEPP 46 contain a number of exceptions where landowners do not need to apply for consent to clear:

- clearing rates < than 2ha/yr
- lopping for stock fodder
- clearing for utility infrastructure;
- regrowth < than 10 years old.

There is a complex series of guidelines contained in:

- State Environmental Planning Policy #46: Protection and management of Native Vegetation Definitions and Exemptions, 1996"
- "Planning Guidelines for Native Vegetation Protection and Management in NSW: Our native vegetation is our heritage, 1995"
- "Planning Guidelines for Native Vegetation Protection and Management in NSW, Supplement #1, 1996"
- Report on "Native Vegetation Management in NSW, August 1996"

The officers reported that as dry land grazing has become less sustainable there is pressure for the release of land for urban or hobby farm development. There is also a high need for an accurate map of native vegetation on private land and for such a map to recognise *E. tereticornis* open forest grassland, and dry grassy eucalypt woodlands and related communities. It was suggested that about 4 per cent of this type remains in the Bega valley.

There is a multiplicity of Acts in NSW dealing with environmentally sustainable land use which needs consolidation. Examples are the water Act, Rivers and Foreshores Improvement Act, Catchment management Act, Threatened Species Conservation Act, Soil Conservation Act, and the Clear Waters Act.

The establishment of plantations on private land currently raises the following issues:

- The retention of native vegetation along streams;
- Road location, construction and maintenance;
- Confidence in the Timber Harvest Guarantee Act is shaky due to the provisions of the Threatened Species Act.