CASINO MANAGEMENT AREA EIS AND MURWILLUMBAH MANAGEMENT AREA EIS SUPPORTING DOCUMENT No. 2

AQUATIC ENVIRONMENT SURVEY REPORT CASINO AND MURWILLUMBAH MANAGEMENT AREA NORTHERN REGION STATE FORESTS OF NEW SOUTH WALES

by

David Balloch

1993

STATE FORESTS
NORTHERN REGION

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CASINO AND MURWILLUMBAH MANAGEMENT AREAS
NORTHERN REGION
STATE FORESTS OF NEW SOUTH WALES

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David Balloch

for
State Forests of New South Wales

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The findings of this report are based on the author's analysis and interpretation of the survey results. Views and interpretations presented in the report are those of the author and not necessarily those of the State Forests of New South Wales. The recommendations of the report are the opinion of the author.

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1. Introduction

This report assesses the environmental effects of the proposed forestry operations and their interaction with natural factors on the aquatic environments of the Casino District, which is comprised of the Casino Management Area (CMA) and the Murwillumbah Management Area (MMA).

Progressive forestry operations may generate on-site cumulative effects by modifying soil and vegetation composition, slope stability and surface erosion potential. In addition, this temporal sequence can impact off-site resources such as stream water quality, channel sedimentation, riparian vegetation, aquatic habitats and stream hydrology.

Environmental issues relating to hydrology, water quality, aquatic biological communities and aquatic resource use of rivers and streams draining State forests in the CMA and MMA are discussed.

The report is structured in four parts:

- Existing Aquatic Environment
- Review of Literature
- Environmental Impacts and Safeguards
- Environmental Monitoring Program

2. Existing Aquatic Environment

The existing aquatic environment is described below in terms of catchment characteristics, hydrology, water quality, aquatic biology and water supplies.

2.1 Catchment Characteristics

2.1.1 General

General descriptions of catchment characteristics are given below for the CMA and the MMA.

Casino Management Area

The main river systems of the CMA comprise the Richmond and Clarence Rivers (Figure 1). The Richmond Range runs north/south through the length of the CMA, forming the watershed between the Clarence River to the west and the Richmond River to the east. The northern end of the Gibraltar Range forms the watershed between the Clarence and Timbarra Rivers, south from their confluence at Tabulam.



Note: Also refer to Figure 9.1 in Volume A of the Casino Management Area EIS

CASINO AND MURWILLUMBAH MANAGEMENT AREAS

LEGEND

CASINO

- CS10 Saltwater Creek
- CS11 Batten's Bight
- CS12 Barrett's Creek
- CS13 Desert Creek
- CS14 Cedar Creek
- CS15 Ewingar Creek
- CS16 Gorge Creek
- CS17 Myrtle Creek
- CS18 Mongogarie Creek
- CS19 Sandy Creek

MURWILLUMBAH

- MW20 Boomerang Creek
- MW21 Coopers Creek
- MW22 Wilson's Creek
- MW23 Cudgera Creek
- MW24 Byrill Creek
- MW25 Wollumbin Creek

WATER SAMPLING STATION

MANAGEMENT BOUNDARY

TOWNS

ROADS

RIVERS

0 20km

N

STREAM SAMPLING STATIONS

FIGURE 1

Major tributaries of the CMA are the south-flowing Wilson's River which joins the Richmond River at Coraki, and Bungawalbin Creek which flows north and joins the Richmond River below its confluence with Wilson's River.

In general the CMA is characterised by a high proportion of flat to gently undulating country with 60% of the State forests in the slope class range of 0 to 5%, 30% in the 5-10% slope class and the remainder on slopes over 10%.

Both the Clarence and Richmond River catchments have expansive floodplain areas, making the flat terrain a topographic feature of the CMA. The topography of Richmond Range is undulating on the lower slopes but becomes steeper at higher elevations. Some steep slopes are also associated with the MacKellar Range in the north. Parts of State forests located on the west side of the Richmond Range (Richmond Range, Cherry Tree, Mt. Belmore, and Mt. Marsh State forests) drain to the Clarence River, and the remaining parts of the same State forests drain eastwards to the Richmond River.

Most of the low-lying and coastal State forests (Doubleduke, Tabbimoble, Myrtle, Bungawalbin, Camira and parts of Gibberagee State forests) drain to the Richmond River via Bungawalbin Creek, with a few State forests (Bungawalbin, Mororo, Banyabba and parts of Gibberagee State forests) draining southwards to the lower Clarence River.

The topography of the Ewingar forests is moderate on the Gibraltar Range plateau, but very steep to precipitous on the falls into the major rivers. The major State forests (Ewingar and parts of Washpool and Billilimbra) straddle the Gibraltar Range and drain directly to the Clarence River on the east side and indirectly to the Clarence River via the Timbarra River (Billilimbra and parts of Ewingar State forests) on the west side.

Most of the larger upland State forests play an important role in protecting catchment values, both in terms of maintaining water quality and in lowering the peak intensity of minor floods.

Murwillumbah Management Area

The MMA is located in the far northeast corner of New South Wales and the State forests are situated on the broken mountainous ranges forming the upper catchments of the Tweed, Brunswick and Wilson's Rivers (Figure 1). The Tweed and Brunswick Rivers drain directly to the South Pacific Ocean, whereas Wilson's River drains to the Richmond River, thence to the ocean. The major river basin is the Tweed River which has a rugged and compact catchment of 1100 km^2 in area.

The Tweed River receives drainage from parts of Nullum and Mooball State forests, Wilson's River receives drainage from several State forests (Whian Whian, Whian Whian East and Goonengerry State forests), and the Brunswick River receives drainage from parts of Nullum State forest on the eastern side of the Koonyum Range.

A major tributary of the Tweed River is Oxley River which rises in the Tweed Range in the west and receives drainage from both Mebbin and Wollumbin State forests.

The State forests are either elevated above the countryside and separated from it by steep slopes or cliffs which in many cases form natural boundaries (Whian Whian State forest and the southern half of Nullum State forest), or are generally hilly, rising steadily up from adjacent farm lands (Mooball, Mebbin, and Wollumbin State forests, and the northern half of Nullum State forest). Some very steep slopes are associated with the Tweed Range in the far west, and with the Nightcap and Koonyum Ranges in the central area.

Elevation ranges from 50 m above sea level (a.s.l.) in the coastal foothills to 1100 m a.s.l. on the Tweed Range, with most State forests lying between 200 and 700 m a.s.l.

2.2.2 Catchment Climate and Rainfall

Climate and rainfall in the catchments of the CMA and MMA are described separately below.

Casino Management Area

The climate is warm sub-tropical, with high summer/autumn rainfall and a dry winter and spring. The climate in the higher altitude State forests of the Gibraltar Range tends towards warm temperate.

At Casino, mean annual rainfall is around 1100 mm and the highest annual total recorded was 1955 mm. There is a distinct wet period from December to March, when about half the rainfall is received. The months of August and September are relatively dry and receive about 10% of the total annual rainfall. The mean annual rainfall at Mt. Pikipene headquarters is 1169 mm. In the northern part of the Richmond Range, mean annual rainfall is about 1360 mm reducing to 1050 mm towards the southern part. Estimates of mean annual rainfall in the Ewingar forests are 1425 mm at higher altitudes falling to 1050 mm at lower altitudes.

The driest portion of the catchment is along the the valleys of the middle reaches of the Richmond River and major tributaries, where mean annual rainfall is less than 1100 mm. Highest annual totals in excess of 1600 mm are recorded on the high ground along the ridge that divides the catchment from that of the Tweed River.

When a depression is located off the coast of northern NSW or southern Queensland heavy rains may occur. Under these conditions rainfall intensities of 230 mm in 24 hours are not uncommon.

Prolonged dry periods accompanying dry north-westerly winds from continental high pressure systems and low rainfall can lead to greatly reduced flows in forest streams, as well as creating high bushfire danger. Cyclonic rains moving south from Queensland can cause extensive flooding, especially in the Ewingar forests where destructive flash floods have been reported.

Murwillumbah Management Area

Climate of the MMA is subtropical with a well-defined summer-autumn rainfall maximum. The wettest months are normally December to April, and the driest months August and September.

A marked wet season extends from December to April, during which 60% of the annual total rainfall occurs. Rainfall is high due to the mountainous topography close to the coast. Mean annual rainfall is in the range 1400 to 2985 mm depending on altitude. Mt. Nardi on the Nightcap Range has the highest recorded rainfall values in NSW (2985 mm average for the period 1967-1976). The coastal fringe receives rainfall in excess of 1650 mm.

Tropical cyclones moving down the Queensland coast enter the MMA and cause damage through windthrow and breakage from the associated strong winds and high intensity rain storms. Cyclonic disturbances are capable of producing rainfall intensities of 250 mm in 24 hours and monthly totals greater than 450 mm have been recorded. The cyclones are prevalent in the warmer summer/autumn months.

The occurrence of strong north-westerly winds from continental high pressure systems, together with rising temperatures and low rainfall, can cause periods of low or zero flows in many streams draining the State forests, as well as causing fire danger, during the period August to December.

2.2.3 Catchment Land Use

Land uses and activities within catchments that may influence the aquatic environments of the CMA and MMA are summarised below.

Casino Management Area

The geographical diversity of the Richmond River catchment allows for a wide range of land use activities that may influence the aquatic environment. In the lower valley much of the original vegetation has been entirely removed, particularly where soil and gentle topography have favoured pastoral land use. Extensive grass lands for grazing and dairying are common in the middle and lower Richmond valley.

The floodplain of the Richmond River has a wider range of land use activities including, grazing (principal land use), sugar growing, dairying, intensive cropping and limited forestry. The main land use of grazing is likely to be a continuing source of sediment and nutrient loading to the Richmond River system.

The degree of forest cover in catchments upstream of sampling stations established during a reconnaissance survey of streams in the CMA are given in Table 1. These sampling stations were established as part of the water quality and aquatic biological field program on 23rd and 24th March 1992.

Table 1 reveals that all the catchments above the 10 stream sampling stations are mostly forested, varying from 64% to 99% forest cover; therefore, stream water quality is most likely to be influenced by forest hydrology. The remaining

percentages of non-forested catchment area were comprised mainly of farm land used for grazing and, or, swamps and unproductive land.

Murwillumbah Management Area

A significant portion of the Upper Tweed River catchment is under forest cover and is used primarily as a timber resource. Considerable areas of the catchment are also reverting to forest cover after unsuccessful grazing attempts. The reversion to forest cover is helping to arrest the severe erosion that developed during clearing. Erosion of soils from banana plantations also contribute sediment loads to the Tweed River, especially in its lower reaches.

Limited grazing and dairying activities on bordering hills and lands below the forested catchments are the main agricultural land uses. The main agricultural activities in the lower Tweed valley are growing vegetables and tropical crops such as banana and sugar cane.

Water quality in the Tweed River is probably adversely affected by agricultural activities, particularly sugar growing, flood mitigation and urban runoff from Murwillumbah. Wastewater discharges from the Condong sugar mill have a significant localised impact on a section of the river.

The degree of forest cover in catchments upstream of sampling stations established during a reconnaissance survey of streams in the MMA are given in Table 1. These sampling stations were established as part of the water quality and aquatic biological field program on the 24th March 1992.

Table 1 reveals that all the catchments above the 6 stream sampling stations are mostly forested, varying from 48.5% to 99% forest cover; therefore, stream water quality is most likely to be influenced by forest hydrology. The remaining percentages of non-forested catchment area were comprised mainly of farm land used for grazing and limited crop growing.

2.3 Hydrology

2.3.1 General

Knowledge of the hydrological conditions prevailing in rivers of the CMA and MMA, particularly in the streams draining State forest catchments, is fundamental to assessing the proposed forestry operations, their interaction with natural factors, and their effects on stream hydrology.

Table 1

List of sampling stations established in the Casino and Murwillumbah Management Areas and percentage of forest and non-forest land use in the catchments upstream of the stations

Sampling station		State forest(s) represented	*Catchment area (ha)	% Catchment	
Code	Name			Forested	Non-forested
Casino Management Area:					
CS10	Saltwater Creek	Banyabba	3775	99.0	1.0
CS11	Batten's Bight	Camira/Mt Marsh	2675	89.9	10.1
CS12	Barrett's Creek	Mt Marsh	6750	64.0	36.0
CS13	Desert Creek	Washpool	2975	99.0	1.0
CS14	Cedar Creek	Ewingar	2263	99.0	1.0
CS15	Ewingar Creek	Ewingar	6700	99.0	1.0
CS16	Gorge Creek	Richmond Range	4350	83.3	16.7
CS17	Myrtle Creek	Mount Belmore	10575	90.5	9.5
CS18	Mongogarie Creek	Cherry Tree	9450	89.4	10.6
CS19	Sandy Creek	Ellangowan/Braemar	11900	71.3	28.4
Murwillumbah Management Area:					
MW20	Boomerang Creek	Whian Whian	812	77.0	23.0
MW21	Coopers Creek	Nullum	1150	90.0	10.0
MW22	Wilson's River	Nullum	1400	90.0	10.0
MW23	Cudgera Creek	Mooball	612	48.5	51.5
MW24	Byrill Creek	Mebbin	1500	99.0	1.0
MW25	Wollumbin Creek	Wollumbin	287	86.1	13.9

* Catchment area upstream of sampling stations, determined planimetrically from FCNSW maps.

Flow data provides information on the capacity of streams to transport sediments and other contaminants mobilised by forestry operations and their capacity to attenuate their concentrations by dilution.

2.3.2 Stream Flows

Flow duration data for gauged rivers and streams in the CMA and MMA are given in Table 2 (Department of Water Resources, 1992 data).

High flows, flows that can be expected most of the time (median), and low flows are represented by flow durations of 10%, 50% and 90% exceedence respectively in Table 2. Exceedence flow is that flow which is equalled or exceeded for a given percentage of the time.

Table 2

High, median and low flow duration data for gauged rivers and streams within the Casino and Murwillumbah Management Areas

Gauging station	Exceedence flow (†ML/d)		
	10%	50%	90%
Casino Management Area:			
Richmond River catchment:			
Richmond River at Casino	2942.3	382.8	72.9
Batten's Bight at Camira crossing	34.8	2.3	0.000
Clarence River catchment:			
Clarence River at Baryulgul	7985.1	1043.1	244.6
Clarence River at Tabulam	4318.8	386.2	33.1
Sportsman Creek at Gurranang	223.6	12.0	0.030
Washpool Creek at Lionsville	802.9	106.3	31.5
Timbarra River at Drake	2066.1	342.8	83.4
Gorge Creek at Bonalbo	32.71	2.9	0.001
Peacock Creek at Bonalbo	41.3	7.8	0.320
Murwillumbah Management Area:			
Tweed River catchment:			
Tweed River at Kunghur	144.8	15.6	2.097
Oxley River at Tyalgum	477.2	48.2	9.525
Oxley River at Eungella	853.5	88.6	17.3
Richmond River catchment:			
Wilson's River at Goonengerry	235.7	41.7	5.280
Wilson's River at Federal	261.8	28.4	6.207
Shannon Brook at Yorklea	439.1	37.8	1.643
Rocky Creek at Gibbergunyah Range road	188.8	8.3	1.236
Coopers Creek at Repentence	456.5	51.7	8.603

† megalitres per day.

(After Department of Water Resources, 1992 data)

The extensive nature of the Richmond River catchment and variable rainfall distribution provide a range of different flow regimes within the system at any one time. Highest runoff occurs in late summer, although significant flows occur throughout the whole year; this variability is typical of rivers in the North Coast region of New South. Smaller creeks draining both upland and low-lying coastal State forests may be ephemeral, drying up during protracted periods of little or no rainfall. During the March 1992 reconnaissance survey, several streams were dry, for example, Filans Creek (Myrtle State forest), Six Mile Waterhole Creek

(Gibberagee State forest) and small streams draining the low-lying State forests of Doubleduke, Tabbimoble and Devil's Pulpit.

The Clarence River is the largest of the North Coast rivers and has a catchment area of 22,700 km^2. The median or 50% exceedence flow at Baryulgul is 1043 ML/d. The Richmond River has catchment area of 6900 km^2 and the 50% exceedence flow at Casino is 383 ML/d. Major creeks draining State forests in the CMA, and monitored by the Department of Water Resources, are Gorge Creek (median flow of 2.9 ML/d) and Batten's Bight (median flow of 2.3 ML/d). The Tweed River has a smaller catchment area of 1100 km^2 and the 50% exceedence flow at Eungella near Murwilllumbah is 89 ML/d.

Additional flow estimates are given in Section 2.4.4 (Table 4) for a number of forested streams draining selected State forests.

2.4 Water Quality

2.4.1 General

Water quality monitoring is a vital component of any environmental impact assessment program. The objective of water quality monitoring at both the feasibility and post-EIS stage is the collection of baseline data against which future changes can be compared and assessed, and significant deviations from normal cyclical fluctuations be detected.

The Aquatic Environment Consultant was commissioned to carry out a reconnaissance survey to characterise existing water quality of forest streams draining the State forests in the CMA and MMA. Since the once-off field survey gives a synoptic picture of water quality only at the time of sampling, baseline and longer term sampling of selected streams are key components recommended for inclusion in the FCNSW's regional monitoring program (Section 5).

Water quality characteristics of the principal river systems were extracted from the State Pollution Control Commission's Northern Rivers Study for the Clarence River (SPCC 1987a), Richmond River (SPCC 1987b) and the Tweed-Terranora Estuary (SPCC 1985). Additional water quality data on turbidity and total phosphorus were extracted from Bek & Robinson (1991).

2.4.2 Water Sampling and Measurements

A two-day reconnaissance survey was undertaken on the 23rd and 24th March 1992 to sample the water of streams draining selected State forests in the CMA and on 25th March 1992 for the MMA. Table 3 gives details of the 16 sampling stations that were established on representative creeks having sub-catchments within the selected State forests. An additional two streams were visited, but were not sampled owing to non-flow or stagnant conditions.

In situ determinations were made of water temperature, pH, and dissolved oxygen at the time of sampling. Water samples were placed on ice and returned to the

laboratory for analysis. Water analyses were conducted by an NATA-registered laboratory and included determinations of suspended sediments, total dissolved solids, alkalinity, conductivity, reactive phosphorus and oxidised nitrogen. Analytical methods conformed to international standard methods (APHA 1985). Parameter selection was based on consideration of the likely impacts from forestry operations on stream water quality, and on the need to characterise the streams in terms of other parameters relevant to the assessment of ecological effects.

Table 3

Water quality sampling stations established on representative streams in the Casino and Murwillumbah Management Areas

Sampling Station		State forest(s)	*Catchment	Drainage
Code	Name	Represented	area (ha)	Basin
Casino Management Area:				
CS10	Saltwater Creek	Banyabba	3775	Clarence
CS11	Batten's Bight	Camira/Mt Marsh	2675	Richmond
CS12	Barrett's Creek	Mt Marsh	6750	Richmond
CS13	Desert Creek	Washpool	2975	Clarence
CS14	Cedar Creek	Ewingar	2263	Clarence
CS15	Ewingar Creek	Ewingar	6700	Clarence
CS16	Gorge Creek	Richmond Range	4350	Clarence
CS17	Myrtle Creek	Mount Belmore	10575	Richmond
CS18	Mongogarie Creek	Cherry Tree	9450	Richmond
CS19	Sandy Creek	Ellangowan/Braemar	11900	Richmond
Murwillumbah Management Area:				
MW20	Boomerang Creek	Whian Whian	812	Richmond
MW21	Cooper's Creek	Nullum	1150	Richmond
MW22	Wilson's River	Nullum	1400	Richmond
MW23	Cudgera Creek	Mooball	612	ocean
MW24	Byrill Creek	Mebbin	1500	Tweed
MW25	Wollumbin Creek	Wollumbin	287	Tweed

* Catchment area upstream of sampling station.

2.4.3 Regional Water Quality

Regional water quality characteristics of gauged rivers and streams of the CMA and MMA are described below for the major river systems.

Upper Clarence River System

Water quality characteristics of the upper Clarence River and major tributaries are summarised below for the principal water quality variables likely to be influenced by forestry operations.

Suspended sediment

During medium and low flows, total suspended sediment (TSS) concentrations in the upper Clarence River were typically around 4 mg/L. Increased TSS concentrations were evident during high flow conditions, ranging from 8 to 55 mg/L, but most values were in excess of 20 mg/L. The Upper Clarence River at Tabulam was visibly turbid during the field visit of 23rd to 24th March 1992.

Dissolved oxygen

Dissolved oxygen regimes in the upper Clarence River between Baryulgul and Tabulam are generally high. Variation from normal air saturation values (100%) have been known to occur in the upper catchment under high flows due to air entrainment caused by turbulence, for example, records show dissolved oxygen values of 107% saturation at Baryulgul.

Nutrients

Nutrient concentrations as measured by total nitrogen (TN) and total phosphorus (TP) in the upper Clarence River under all flows range from 0.50 to 0.53 mg TN/L and 0.03 to 0.12 mg TP/L respectively at Baryulgul. The TP concentration of 0.12 mg/L recorded at Baryulgul was the highest in the Clarence River. High flow conditions tend to produce a significant increase in nutrient concentrations with most TN concentrations exceeding 0.5 mg/L and with TP concentrations being more variable in the range 0.06 to 0.12 mg/L. These TN and TP concentrations are above the above the threshold levels of 0.5 mg TN/L and 0.05 mg TP/L set by the Australian Environment Council (AEC 1986), and above which stimulation of nuisance algae or macrophytes may be expected to occur.

Soluble nutrients such as total oxidised nitrogen (TON), comprising nitrate- and nitrite-nitrogen, and soluble reactive phosphorus (SRP) were generally less than 0.05 mg/L for a range of flows. However, SRP concentrations equal to 0.05 mg/L have been observed at Baryulgul. In general, most the above soluble nutrient concentrations are below the threshold limits of 500 µg TN/L and 50 µg TP/L set by the Australian Environment Council (AEC 1986), and above which stimulation of nuisance algae or macrophytes may be expected to occur.

Richmond River System

Water quality characteristics of the Richmond River and major tributaries are summarised below for the principal water quality variables likely to be influenced by forestry operations.

Suspended sediment

During low flows, suspended sediment concentrations in the upper catchment of the Richmond River were typically between 3 and 5 mg/L but were higher, between 6 and 10 mg/L, in the estuarine section of the river. Medium flow average TSS concentrations were higher and typically between 6 and 12 mg/L, with high concentrations at Casino (86 mg/L).

Increased TSS concentrations were evident along the whole of the Richmond River during high flow conditions. The concentrations were variable, ranging from 8 to 70 mg/L, but most values were in excess of 25 mg/L. The Richmond River was visibly turbid during the field visit of 23rd to 24th March 1992.

Dissolved oxygen

Dissolved oxygen (DO) regimes in the non-tidal reaches of the Richmond River are generally high. Variation from normal saturation values of 100% is evident under low flows and medium flows at various stations along the river. Under low flow conditions, DO levels at Casino and Kyogle were 117% and 46% respectively. Low DO levels have been evident near Woodburn under both medium and high flows when values of 72% were recorded. Supersaturation was also found at Grevillia (116%) during medium flow events.

Nutrients

Nutrient concentrations as measured by total nitrogen (TN) and total phosphorus (TP) in the Richmond River under low flows range from 0.06 to 1.51 mg TN/L and 0.01 to 0.21 mg TP/L. Average TN concentrations during low flows were particularly high (1.51 mg/L) below the confluence with Bungawalbin Creek. Nitrogen concentrations in the mainstream gradually decline towards the estuary.

During medium flows, nutrient levels were more uniform with TN concentrations varying from 0.23 to 1.61 Mg/L. Concentrations of TP were high (0.05 to 0.17 mg/L) along the mainstream, with a gradual downstream decline towards the coast.

Soluble nutrients such as total oxidised nitrogen (TON) comprising nitrate- and nitrite-nitrogen, and soluble reactive phosphorus (SRP) were generally high at many locations along the Richmond River mainstream. Low flow conditions resulted in elevated TON concentrations of around 0.12 mg/L downstream of Bungawalbin Creek confluence. TON concentrations upstream of Kyogle and Casino were generally low at around 0.05 mg/L. SRP concentrations were elevated in the mainstream of the Richmond River upstream of Bungawalbin Creek confluence (0.06 mg/L) and at Wiangaree (0.20 mg/L) in the upper catchment. Major peaks in concentration of SRP were associated with mainstream reaches immediately downstream of towns in the catchment, for example, Coraki (0.06 mg/L), Casino (0.11 mg/L), Kyogle (0.08 mg/L and Wiangaree (0.20 mg/L).

In general, total and soluble nutrient concentrations in the Richmond River system regularly exceed the threshold levels of 0.5 mg TN/L and 0.05 mg TP/L set by the

Australian Environment Council (AEC 1986), and above which stimulation of nuisance algae or macrophytes may be expected to occur. Indeed, elevated concentrations of the algal pigment chlorophyll *a* have been observed in the Richmond River mainstream, indicating stimulation of algal populations by nutrient loading.

Tweed River System

Water quality characteristics of the Tweed River system upstream of Murwillumbah weir are summarised below for the principal water quality variables likely to be influenced by forestry operations.

Suspended sediment

Total suspended sediment (TSS) concentrations in the Tweed River under comparable flows in 1978 and 1983 were 10.0 and 5.0 mg/L respectively at Murwillumbah weir (SPCC 1985). Increased TSS concentrations were evident during high flow conditions, a TSS value of 35 mg/L was observed upstream of Murwillumbah weir during high flow conditions.

Bek & Robinson (1991) summarised Department of Water Resources data for turbidity in a tributary of the Tweed River, namely, the Oxley River at Eungella. On the basis of 159 samples collected over a 5-year period, the median and 90-percentile turbidity values were 2 and 8 Nephelometric Turbidity Units (NTU) respectively. The low turbidity values indicate water of good water clarity in the Oxley River and absence of major suspended sediment loading from the catchment.

Dissolved oxygen

Dissolved oxygen regimes in the Tweed River upstream of the Murwillumbah weir ranged from 93% to 112% saturation. Variation from normal saturation values have been known to occur upstream of the weir, where low dissolved oxygen levels of 30% saturation have been recorded and attributed to very low flows and stagnating water at depth. Fast-flowing reaches of the Tweed River and its tributaries in the upper catchment are expected to have dissolved oxygen regimes ^{3}100% saturation.

Nutrients

Nutrient concentrations as measured by total nitrogen (TN) and total phosphorus (TP) in the Tweed River under comparable flows in 1978 and 1983 were 0.08 and 0.43 mg TN/L and 0.03 and 0.06 mg TP/L respectively, upstream of Murwillumbah weir. During an additional water quality study carried out in January 1984 (SPCC 1985), TN and TP concentrations upstream of Murwillumbah weir ranged from 0.23 and 0.47 mg/L and from 0.073 and 0.08 mg/L respectively. For most of the time TN and TP concentrations in the Tweed River are below the threshold levels of 0.5 mg TN/L and 0.05 mg TP/L set by the Australian Environment Council (AEC 1986), above which nuisance algal or macrophytic growths could be expected. However, TP concentrations in the January 1984 study (SPCC 1985) exceeded the threshold

limit of 0.05 mg/L and occasional elevations in chlorophyll *a* concentrations have been observed (SPCC 1985).

Bek & Robinson (1991) summarised Department for Water Resources data for TP in a tributary of the Tweed River, namely, Oxley River at Eungella. On the basis of 71 samples collected over a 5-year period, the median and 90-percentile TP concentrations were 0.05 and 0.10 mg/L, respectively. These TP concentrations equal or exceed the threshold level of 0.05 mg/L set by the Australian Environment Council (AEC 1986), above which nuisance algal or macrophytic growths could be expected. Indeed, chlorophyll *a* concentrations have been shown to be elevated in the river section between just upstream of Murwillumbah and the Tweed estuary near Chinderah. The potential therefore exists for stimulation of algal and plant growth in the lower reaches of the Tweed River, especially during low flow conditions.

Soluble nutrients such as total oxidised nitrogen (TON), comprising nitrate-nitrogen and nitrite-nitrogen, and soluble reactive phosphorus (SRP) were generally less than 0.05 mg/L for a range of flows. During the January 1984 survey, TON concentrations ranged from non-detectable to 0.015 mg/L and SRP concentrations ranged from 0.02 to 0.03 mg/L. These concentrations of soluble nutrients are low, and below threshold limits set by the Australian Environment Council (AEC 1986) for total nutrient concentrations.

2.4.4 Local Water Quality

Local water quality characteristics of streams sampled in the CMA and MMA during the field survey are described below.

Casino Management Area

Table 4 presents water quality analyses of 10 streams draining State forests in the CMA. It is important to note that these analyses are based on a once-off sampling effort and, therefore, represent water quality only at the time of sampling.

In general, forested catchment streams of the Gibraltar Range were of good water quality, as represented by high dissolved oxygen saturations (³100%) and low suspended sediment concentrations ranging from 0.6 mg/L (Cedar Creek) to 1.2 mg/L (Desert Creek). The catchments of these two creeks were 99% forested, indicating the effectiveness of water quality protection by the forests.

Streams draining the State forests of the Richmond Range and Mount Belmore area were of lower quality having generally high dissolved oxygen regimes (85% to 100% saturation) but also having elevated suspended sediment concentrations ranging from 6.4 mg/L (Sandy Creek) to 17.8 mg/L (Barrett's Creek).

Table 4

Water quality characteristics of forest streams in the Casino Management Area (March 23rd to 24th 1992)

Sampling Station# =	CS10	CS11	CS12	CS13	CS14
Estimated flow (m^3/s)	0.05	<0.01	<0.01	2.0	1.0
Temperature (°C)	21.0	25.0	22.0	17.5	21.0
Dissolved oxygen (mg/L)	7.1	7.8	6.2	8.8	7.4
pH	6.20	6.56	6.69	6.86	6.51
Total suspended solids (mg/L)	2.4	8.4	19.6	1.2	0.6
Total dissolved solids (mg/L)	133.0	92.0	197.0	53.0	65.0
Alkalinity (mg $CaCO_3$/L)	21.2	8.8	47.4	22.1	23.2
Specific conductance (µS/cm)	202.0	120.0	336.0	67.0	76.0
Reactive phosphorus (µg/L)	<2.0	<2.0	<2.0	<2.0	<2.0
Oxidised nitrogen (µg/L)	<5.0	25.0	<5.0	<5.0	<5.0
Sampling station# =	CS15	CS16	CS17	CS18	CS19
Estimated flow (m^3/s)	3.0	0.1	3.0	2.0	<0.01
Temperature (°C)	19.8	22.0	23.0	27.0	21.5
Dissolved oxygen (mg/L)	8.5	7.3	8.0	7.4	7.5
pH	6.45	7.54	6.98	7.45	6.46
Total suspended solids (mg/L)	17.0	3.0	17.8	13.6	6.4
Total dissolved solids (mg/L)	87.0	232.0	98.0	142.0	156.0
Alkalinity (mg $CaCO_3$/L)	13.0	120.0	23.4	54.3	31.7
Specific conductance (µS/cm)	67.0	410.0	129.0	222.0	268.0
Reactive phosphorus (µg/L)	3.0	22.0	2.0	7.0	2.0
Oxidised nitrogen (µg/L)	13.0	17.0	11.0	16.0	18.0

See Table 1 for station names;

The catchments of these two creeks were only 71% (Sandy Creek) and 64% (Barrett's Creek) forested, possibly indicating the influence of non-forested catchment land uses on water quality.

In general, streams draining low-lying areas of the CMA (e.g., Banyabba State forest) were of intermediate water quality compared to those streams draining the Gibraltar Range and Richmond Range/Mount Belmore area. The dissolved oxygen concentration in Saltwater Creek (Banyabba State forest) was 7.1 mg/L (75% saturation) and the suspended sediment concentration was 2.4 mg/L. The catchment of Saltwater Creek was 99% forested, indicating water quality protection by forested lands.

Flow discharge-water quality variable relationships need to be characterised by additional low-flow and flood-flow sampling which are monitoring components recommended for inclusion in the FCNSW's regional monitoring program (see Section 5).

Summaries of the principal water quality variables likely to be affected by forestry operations are given below.

Temperature

The principal factors influencing stream water temperatures are seasonality and flow rate. Water temperatures in the streams draining State forests of the CMA ranged from 17.5°C in Desert Creek (Washpool State forest) to 27.0 °C in Mongogarie Creek (Cherry Tree State forest). Much of the variability in temperature between the streams was accounted for by the time of day when sampling was undertaken. Generally, those streams sampled early morning showed lower temperatures than streams sampled later in the afternoon, when stream temperatures tended to rise during the day. If the forest streams had all been sampled for water temperature at the same time of day, then differences in water temperature would have tended to reflect differences in altitude and the degree of shade provided by riparian forest canopies. It is to be expected that forest headwater streams will be several degrees cooler than downstream reaches of the main river systems, as confirmed by SPPC (1987a).

pH

The pH levels of the forest streams were all slightly acidic, ranging from pH 6.20 in Saltwater Creek (Banyabba State forest) to pH 7.54 in Gorge Creek (Richmond Range State forest). Other streams showed intermediate pH levels.

Variability in pH between forest streams at the time of sampling can probably be explained by differences in mineralisation within the State forest catchments and perhaps differences in flow regimes (pH-discharge relationships). In general, stream water pH falls during high discharge events.

Suspended sediments

Total suspended sediment (TSS) concentrations were generally low in the 10 streams sampled, lying in the range 2.4 to 8.4 mg/L. The lowest TSS concentrations were observed in streams draining the State forests of the Gibraltar Range, for example, Cedar Creek (0.6 mg/L) and Desert Creek (1.2 mg/L). An exception was Ewingar Creek which drains Ewingar State forest, and which had a TSS concentration of 17 mg/L. This high level was unexplained, especially since Ewingar Creek catchment was 99% forested; however, flash flooding in the past has caused river bank erosion and instability, and the elevated TSS concentration observed during the field visit may reflect residual effects from erodible sources within the catchment.

The highest TSS concentrations were observed in those streams draining the Richmond Range forests. TSS concentrations in streams draining the State forests of the Richmond Range and Mount Belmore showed wide variation, ranging from 3 mg/L in Gorge Creek (Richmond Range State forest) to 19.6 mg/L in Barrett's Creek (Mt. Marsh State forest). In general, higher TSS concentrations were found in those streams having a significant non-forested land use, for example, pasture and farming areas. The highest TSS concentration of 19.6 mg/L observed for Barrett's Creek, may reflect the fact that the catchment was only 64% forested.

A wide variation in TSS concentrations was observed in those streams draining the State forests of the undulating or low-lying terrain of the Richmond River valley. TSS concentrations ranged from 2.4 mg/L in Saltwater Creek (Banyabba State forest) to 6.4 mg/L in Sandy Creek (Ellangowan/Braemar State forests). Saltwater Creek catchment is 99% forested compared to a value of 71% for Sandy Creek; therefore, non-forest land uses may contribute to the higher suspended sediment loading of Sandy Creek.

TSS values of less than 5 mg/L are typical of low to median flows in streams draining relatively undisturbed forested catchments, and show the importance of forests in protecting catchment values and downstream water quality.

Dissolved oxygen

Dissolved oxygen (DO) concentrations in streams of the CMA were generally high, ranging from 6.2 mg/L (Å70% saturation) in Barrett's Creek (Mt. Marsh State forest) to 8.8 mg/L (100% saturation) in Desert Creek (Washpool State forest). DO concentrations values in this range are not inimical to the maintenance of viable fisheries.

Total ionic composition

Total mineralisation or ionic concentration is reflected by the measurements of both specific conductance and total dissolved solids (TDS). Specific conductance is strongly influenced by differences in the types or proportions of minerals in each catchment. Specific conductivities ranged from 67 µS/cm in Desert Creek (Washpool State forest) to 410 µS/cm in Gorge Creek (Richmond Range State forest). The corresponding TDS concentrations ranged from 53 to 232 mg/L respectively.

Soluble nutrients

Soluble nutrient concentrations, as determined by total oxidised nitrogen (TON) comprised of nitrate- and nitrite-nitrogen, and soluble reactive phosphorus (SRP), were low in all stream waters sampled. Very low TON concentrations of <5 µg/L were recorded in water samples from four of the ten streams sampled (Table 4). The highest TON concentration of 25 µg/L was recorded in Battens' Bight Creek (Camira/Mt. Marsh State forests). Detectable TON concentrations in the remaining streams ranged from 11 µg/L in Myrtle Creek (Mount Belmore State forest) to 18 µg/L in Sandy Creek (Ellangowan/Braemar State forests). In general, the lowest

TON concentrations were observed in those streams draining State forests in the Gibraltar Range.

SRP concentrations were very low in streams draining the Ewingar forests, ranging from <2.0 µg/L in both Desert Creek (Washpool State forest) and Cedar Creek (Ewingar State forest) to 3.0 µg/L in Ewingar Creek (Ewingar State forest). The catchments of these three streams were 99% forested, indicating the small leaching losses from the State forests. The highest SRP concentration (22 µg/L) was observed in Gorge Creek (Richmond Range State forest), with all other streams showing SRP concentrations <7.0 µg/L.

Murwillumbah Management Area

Table 5 presents water quality analyses of six streams draining selected State forests in the MMA. It is important to note that these analyses are based on a once-off sampling effort and, therefore, represent water quality only at the time of sampling. Additional monitoring needs to be undertaken to elucidate flow discharge-water quality variable relationships (see Section 5).

In general, streams draining the upland State forests (Mebbin, Whian Whian, Whian Whian East, Nullum and Wollumbin) were generally of high water quality, as represented by high dissolved oxygen concentrations in the range 7.7 mg/L (Å85% saturation) to 9.1 mg/L (100% saturation) and low suspended sediment concentrations in the range 1.2 to 2.4 mg/L. Most of the catchments above the sampling stations for the upland streams were forested (between 77% and 99% cover) and this has afforded downstream protection of water quality in terms of low suspended sediment loadings.

Water quality of streams draining the coastal State forests (e.g., Mooball) was good in terms of high dissolved oxygen, but higher suspended sediment concentrations reflected sediment inputs from non-forest land uses such as grazing and agricultural lands (51% of stream catchment).

Summaries of the principal water quality variables likely to be affected by forestry operations are given below.

Temperature

Water temperatures in the forest streams ranged from 18.0°C in Wilson's River (Nullum State forest) to 27.5 °C in Wollumbin Creek (Wollumbin State forest). Much of the variation in the water temperatures of the streams sampled was attributable to time of day when measurements were taken. The higher water temperatures in Wollumbin Creek was partly due to late afternoon sampling and the fact that this creek was not fully shaded, with only 86% of the catchment being forested. The second highest water temperature was observed in Cudgera Creek, which had the least shade (only 48% of catchment forested).

Table 5

Water quality characteristics of forest streams in the Murwillumbah Management Area (March 24th 1992)

Sampling Station# =	MW20	MW21	MW22	MW23	MW24	MW25
Estimated flow (m^3/s)	1.0	3.0	3.0	0.05	<0.01	<0.01
Temperature (°C)	18.7	18.0	19.2	22.5	20.3	27.5
Dissolved oxygen (mg/L)	8.5	8.8	9.0	7.8	7.7	9.1
pH	6.62	6.83	6.60	6.47	7.18	6.66
Total suspended solids (mg/L)	1.2	1.6	1.4	9.0	2.0	2.4
Total dissolved solids (mg/L)	59.0	61.0	53.0	76.0	169.0	85.0
Alkalinity (mg $CaCO_3$/L)	7.7	11.3	8.6	8.7	38.8	18.3
Specific conductance (µS/cm)	59.0	60.0	55.0	104.0	290.0	121.0
Reactive phosphorus (µg/L)	11.0	19.0	<2.0	<2.0	7.0	<2.0
Oxidised nitrogen (µg/L)	37.0	44.0	27.0	<5.0	6.0	<5.0

See Table 1 for station names.

The lowest water temperatures were recorded in streams draining the State forests of the Tweed Range (e.g., Mebbin State forest), indicating an altitudinal temperature effect. It is to be expected that forest headwater streams will be several degrees cooler than downstream reaches of the Tweed River.

If stream temperatures could have been determined at the same time of day, then differences in water temperature would have tended to reflect differences in altitude and the degree of shade provided by riparian forest canopies.

pH

The pH levels of the forest streams were all slightly acidic to neutral, ranging from pH 6.60 in Wilson's River (Nullum State forest) to pH 7.18 in Byrill Creek (Mebbin State forest). Most streams at the time of sampling had pH regimes just below neutral pH.

Variability in pH between streams can probably be explained by differences in mineralisation within the State forest catchments and perhaps differences in flow regimes (pH-discharge relationships). In general pH tends to lower during high flow events.

Suspended sediments

Total suspended sediment (TSS) concentrations were very low in streams draining the upland State forests, lying in the range 1.2 to 2.4 mg/L. All the upland streams were non-turbid (high clarity) at the time of sampling. These low TSS values,

generally less than 5 mg/L, are typical of low to median flows in streams draining relatively undisturbed forested catchments, and show the importance of forests in protecting catchment values and downstream water quality.

The highest TSS concentration of 9.0 mg/L was observed in Cudgera Creek (Mooball State forest) which was visibly turbid at the time of sampling. The catchment of this stream was only 48% forested with the remainder being farm land (grazing and dairying).

Dissolved oxygen

Dissolved oxygen (DO) concentrations in all the streams sampled were generally high, ranging from 7.7 mg/L (85% saturation) in Byrill Creek (Mebbin State forest) to 9.1 mg/L (105% saturation) in Wollumbin Creek (Wollumbin State forest). The supersaturated DO level (105%) in Wollumbin Creek may have resulted from full sunshine conditions and attendant high photosynthetic activity of the in-stream vegetation that was present.

Total ionic composition

Specific conductivities ranged rom 55 µS/cm in Wilson's River (Nullum State forest) to 290 µS/cm in Byrill Creek (Mebbin State forest). This was also reflected in the corresponding concentrations of total dissolved solids (TDS) which ranged from 53 to 169 mg/L. This variability probably reflects differences in the mineralogy and soils of the catchments and differences in the supply of major cations and anions.

Soluble nutrients

Soluble nutrient concentrations in the forest streams were variable for both total oxidised nitrogen (TON) comprised of nitrate- and nitrite-nitrogen, and soluble reactive phosphorus (SRP) . Very low concentrations of TON (<5 µg/L) and SRP (<2 µg/L) were found in Cudgera Creek (Mooball State forest) and Wollumbin Creek (Wollumbin State forest) and low TON and SRP concentrations of 6 and 7 µg/L respectively, were also recorded in Byrill Creek (Mebbin State forest).

Elevated TON concentrations of 27, 37 and 44 µg/L were observed in Wilson's River (Nullum State forest), Boomerang Creek (Whian Whian State forest) and Coopers Creek (Nullum State forest). These elevated TON concentrations may reflect land use differences, especially the presence of human settlements upstream of the sampling stations. Similarly, elevated SRP concentrations of 11.0 and 19.0 µg/L were observed in Boomerang Creek (Whian Whian State forest) and Coopers Creek (Nullum State forest). Human settlements are located upstream of both Boomerang Creek and Cooper's Creek sampling stations.

All the above soluble nutrient concentrations are below the threshold limits for total nutrients of 500 µg TN/L and 50 µg TP/L set by the Australian Environment Council (AEC 1986), and above which stimulation of nuisance algae or macrophytes may be expected to occur.

2.5 Aquatic Biology

2.5.1 General

Existing aquatic biological environments of the CMA and MMA at the local and regional scales were appraised by literature review and field sampling. At the site scale (State forest streams), the principal aquatic fauna were appraised by literature review (fish) and by sampling (macroinvertebrates). Water-associated fauna such as mammals (including platypuses), amphibians, and reptiles were appraised by a literature search, including data arising from the terrestrial fauna survey (Austeco 1993)

The physical characteristics of the streams have important implications for the distribution and population densities of resident aquatic organisms, and stream habitats can be affected by forestry operations; therefore, important aquatic habitat characteristics were assessed during the field sampling program of 23rd to 25th March 1992.

2.5.2 Aquatic Biological Habitats

Typical physical conditions of stream habitats prevailing at each sampling station are described qualitatively in Table 6 for the CMA and in Table 7 for the MMA. Aquatic habitats at the regional and local scales are described below.

Main River Systems

The main river systems of the CMA and MMA may be divided morphological into upland, lowland and estuarine sections.

Upland Section

The upland section encompasses the headwater streams and tributaries of the rivers of the CMA and MMA, and is characterised by steep gradients, fast flowing water and degrading stream bottoms comprised of boulders, cobbles, gravels and large woody debris.

In the CMA, the upland section includes streams draining State forests of the Gibraltar Range (e.g., Washpool, Billilimbra and Ewingar), and the Richmond Range/Mt. Belmore area (e.g., Cherry Tree and Mt. Belmore). In the MMA, the upland sections include those streams draining State forests of the Tweed Range (e.g., Mebbin), Nightcap Range (e.g., Whian Whian) and the Koonyun Range (e.g., Nullum).

Table 6

Typical physical conditions of aquatic habitats of streams sampled in the Casino Management Area. March 23rd and 24th 1992.

#Sampling Station =	CS10	CS11	CS12	CS13	CS14
Habitat type	RIFFLE	POOL	RIFFLE	RIFFLE	RIFFLE
Presence of turbidity	YES	YES	YES	NO	NO
Gradient (%)	3.0	1.0	1.0	2.0	2.0
Average width (m)	6.0	3.0	2.0	5.0	5.0
Average depth (m)	0.5	1.0	1.0	0.5	0.5
Flow estimate (m^3/s)	0.05	<0.01	<0.01	2.0	1.0
Substratal composition:					
cobble(%)	70	0	0	0	0
gravel (%)	20	10	20	90	90
sand (%)	10	60	50	10	10
mud (%)	0	30	30	0	0
Debris type:					
presence of Coarse POM	YES	YES	YES	YES	YES
presence of Fine POM	YES	YES	YES	YES	YES

#Sampling station =	CS15	CS16	CS17	CS18	CS19
Habitat type	RIFFLE	RIFFLE	RIFFLE	RIFFLE	RIFFLE
Presence of turbidity	YES	YES	YES	NO	YES
Gradient (%)	1.0	0.5	0.5	0.5	0.5
Average width (m)	15.0	3.0	6.0	15.0	2.0
Average depth (m)	2.0	0.5	0.5	0.25	0.5
Flow estimate (m^3/s)	3.0	0.1	3.0	2.0	<0.01
Substratal composition:					
cobble(%)	0	50	0	0	0
gravel (%)	90	40	0	0	40
sand (%)	10	10	100	100	40
mud (%)	0	0	0	0	20
Debris type:					
presence of Coarse POM†	YES	YES	NO	NO	NO
presence of Fine POM	YES	YES	NO	NO	YES

† POM means particulate organic matter.

See Table 1 for sampling station names.

Table 7

Typical physical conditions of aquatic habitats of streams sampled in the Murwillumbah Management Area. March 24th 1992.

#Sampling Station =	MW20	MW21	MW22	MW23	MW24	MW25
Habitat type	RIFFLE	RIFFLE	RIFFLE	RIFFLE	RIFFLE	RIFFLE
Presence of turbidity	NO	NO	NO	YES	NO	NO
Gradient (%)	1.0	4.0	1.0	0.5	1.0	1.0
Average width (m)	10.0	20.0	20.0	2.0	1.5	1.0
Average depth (m)	0.5	1.0	0.5	0.5	0.5	0.25
Flow estimate (m^3/s)	1.0	3.0	3.0	0.05	<0.01	<0.01
Substratal composition:						
cobble(%)	60	80	80	10	80	20
gravel (%)	30	10	10	60	10	50
sand (%)	10	10	10	20	10	20
mud (%)	0	0	0	10	0	10
Debris type:						
presence of coarse POM	YES	YES	YES	YES	YES	YES
presence of fine POM	YES	YES	YES	YES	YES	YES

† POM means particulate organic matter.

See Table 1 for sampling station names.

Lowland Section

The lowland section is characterised generally by large rivers of shallow gradient, slower flowing with aggrading river bottoms comprised of gravels, sands and silts. Further downriver as gradients become shallower still, the lowland section is represented by the floodplain reaches of the main rivers.

Lowland sections in the CMA comprise the mainstream of the upper Clarence River, and the middle and lower reaches of the Richmond and the lower reaches of major tributaries such as Wilson's River and Bungawalbin Creek. Lowland sections in the MMA include the middle and lower reaches of the Tweed River and the lower reaches of its major tributary, the Oxley River.

Estuarine Section

The estuarine section comprises the tidal reaches of the main river systems and the short coastal rivers draining the low-lying coastal State forests of the CMA and MMA. The physical characteristics of the river bed of the estuarine section is

similar to the lowland section described above and the waters are subject to salinity intrusion by brackish and marine waters.

State forest streams (this study)

Evaluation of aquatic habitat types in Tables 6 and 7 indicates that streams draining the upland State forests of the CMA and MMA are structurally more diverse than streams draining the low-lying river valley and coastal State forests. The beds of upland forested streams, such as Desert Creek (Washpool State forest) in the CMA and Byrill Creek (Mebbin State forest) in the MMA, were comprised mainly of a cobble and gravel substratum that provided a large number of microhabitats (e.g., stone surfaces and void space); whereas, the beds of low-lying State forest streams were comprised mainly of sand and mud, representative of a depositing substratum with a reduced number of microhabitats.

In the CMA the stream bottoms of Myrtle Creek (Mt. Belmore State forest) and Mongogarie Creek (Cherry Tree State forest) at the sampling stations were composed entirely of sand (Table 6). This reflected significant sediment loading from unknown erosion sources in the upstream catchment. This type of sand substratum is inimical to aquatic invertebrate life, as the continually shifting bed of sand and the abrasiveness of sand particles precludes successful colonisation and/or maintenance of viable populations. Biological sampling of these two streams revealed no benthic macroinvertebrates to be present.

Large woody debris and other coarse particulate organic matter (CPOM) were prevalent in all upland State forest streams with stony substrata, but was absent in those streams with sandy substrata, for example, Myrtle Creek (Mt. Belmore State forest) and Mongogarie Creek (Cherry Tree State forest). Upland forest streams showed little sign of in-stream vegetation which was more prevalent in stream reaches draining pasture lands downstream of State forest boundaries where tree canopy shade was absent.

Most forest streams sampled in the CMA and MMA showed the presence of fine particulate organic matter (FPOM), which was mainly in the form of fine detritus derived from fragmented and decomposing leaves, bark and other vegetative debris. However, two streams sampled in the CMA (Myrtle and Mongogarie Creeks) had sandy substrata and FPOM was not visually evident.

Stream flows at the time of sampling were estimated by eye; therefore, the flow values in Tables 6 and 7 represent crude estimates. At most sampling stations significant flows were evident at the riffle reaches sampled; however, at Batten's Bight Creek (Camira/Mount Marsh State forests) in the CMA a pool reach was sampled in the absence of any nearby riffle reaches. This slow-flowing and deep habitat influenced the structure of the resident aquatic community.

2.5.3 Aquatic Macroinvertebrate Communities

No comprehensive surveys of the macroinvertebrate communities of the river systems of the CMA and MMA have been carried out; therefore, the

macroinvertebrate communities of representative forest streams in both the CMA and MMA were appraised directly by sampling. Benthic macroinvertebrates were sampled at the ten streams within the CMA and at the six streams within the MMA. Table 1 lists the the sixteen streams sampled.

Macroinvertebrate Sampling

Benthic macroinvertebrate samples were collected by heel-kicking the substratum of riffle reaches for one-minute's duration and using a dip-net having a mesh of 500 µm aperture size. A large number of microhabitats was sampled in order to obtain a representative biological sample from each riffle habitat. Samples were placed on ice in the field and transferred in insulated containers to the laboratory for identification, sorting and enumeration. Identification was taken to species level where possible.

It is emphasised that the once-off sampling of stream macroinvertebrate fauna was undertaken to obtain a "snapshot" picture of the macroinvertebrate populations present in forest streams draining selected State forests. It is acknowledged that the effects of forestry operations on stream macroinvertebrate populations can not be adequately defined by such a brief sampling. Additional macroinvertebrate sampling needs to be conducted to describe baseline conditions, and this is a recommended monitoring component for inclusion in the FCNSW's regional monitoring program (Section 5).

Macroinvertebrate Sampling Results

Descriptions of macroinvertebrate communities inhabiting streams draining selected State forests are described separately below for the CMA and MMA.

Casino Management Area

Community characteristics

The macroinvertebrate communities of streams in the upland State forests of the CMA were typical of 2nd order streams in forested catchments of northern New South Wales and included representatives of widespread faunas in the North Coast region.

The macroinvertebrate communities were dominated by the consumer functional group of 'shredders and scrapers' represented by mayfly nymphs (Ephemeroptera) and caddisfly larvae (Trichoptera). The consumer functional group of 'collectors' was well represented by deposit feeders (midge larvae - Diptera, Chironomidae), but filter feeders (e.g., blackfly larvae - Diptera, Simuliidae) were poorly represented. Superimposed upon the above functional groups was the 'predator' consumer group which was well represented by dragonfly nymphs (Odonata) and the adults and larvae of beetles (e.g., Dytiscidae and unidentified beetles).

The trophic status of the riffle communities of benthic macroinvertebrates inhabiting the forest streams relates directly to the large amount of organic matter imported

from the forests and streamside vegetation. The forests provide large quantities of organic matter in the form of leaves, bark, and woody debris that fall or blow into the streams. Leaves and bark contribute most of the readily usable organic matter in forest streams. After being conditioned (leaching and microbial degradation), leaves and other organic detritus are shredded by the macroinvertebrates groups outlined above. By consuming litter and excreting residues, shredders convert the leaf litter to fine particles and make more food available for the collector consumer groups outlined above.

Species richness

A total of 300 individuals distributed among 26 taxonomic groups (mainly species) of aquatic macroinvertebrate were found in the benthic samples collected from the ten streams in the CMA (Table 8). Generally, streams draining the upland State forests had the largest number of species, for example, 12 species in Desert Creek (Washpool State forest), 13 species in Cedar Creek (Ewingar State forest) and 14 species in Ewingar Creek (Ewingar State forest). The substrata of these three streams were predominantly gravels (90% in each case).

The lowest numbers of species were observed in samples collected from creeks having a predominantly sandy substratum, for example, no macroinvertebrates were present in samples from Mongogarie Creek (Cherry Tree State forest), Myrtle Creek (Mt. Belmore State forest) and Barrett's Creek (Mt. Marsh State forest). Very few macroinvertebrate species are able to colonise and establish populations in a shifting sandy substratum.

The macroinvertebrate communities of streams draining State forests located in the lower catchments of the main rivers and low-lying and coastal areas in the east and south of the CMA were also impoverished. In riffle samples from both Saltwater Creek (Banyabba State forest) and Sandy Creek (Ellangowan/Braemar State forests), only 7 species each were recorded. Only 2 species were found in the sample collected from Batten's Bight Creek (Camira/Mt. Marsh State forests) due to the predominance of sand-sized particles (60%) and the fact that a pool reach was sampled (nearby riffle reaches absent).

Community diversity index

Benthic macroinvertebrate data arising from the aquatic biological sampling program were used to calculate a community diversity index (*d*) based on the Shannon-Wiener function of information theory (Shannon & Weaver 1963) It should be noted that many fast-flowing forest streams of good water quality can have a low diversity because of severe physical conditions. Thus, although a high diversity indicates good quality water, a low diversity does not necessarily indicate poor water quality.

The highest *d*-values of 3.04, 3.08 and 3.21 were recorded in Ewingar Creek (Ewingar State forest), Desert Creek (Washpool State forest) and Cedar Creek (Ewingar State forest) all of which had totally forested catchments.

Table 8

Aquatic macroinvertebrate analyses of benthic samples from streams in the Casino Management Area

Species/Sampling Station	CS10	CS11	CS12	CS13	CS14	CS15	CS16	CS17	CS18	CS19
CRUSTACEA:										
Atyidae										
Parataya australiensis	1				2	2				2
INSECTA:										
Plecoptera										
Illiesoperla australis				1	4	1				
Ephemeroptera										
Caenidae										
Tasmanocoenis sp. A	15	1			2	23	2			9
Baetidae										
Baetidae sp. A						4				5
Leptophlebiidae sp. A										1
Odonata										
Corduliidae										
Nannophlebia risi	1	4				2				
Gomphidae										
Austrogomphus ochraceus							1			1
Trichoptera										
Leptoceridae										
Leptoceridae sp. A				1						17
Triplectides sp. A	1			1	2					
Hydroptilidae sp. A						2				
Hydropsychidae										
Hydropsychidae sp. A							1			
Cheumatopsyche sp. A	1			12	2	5				
Calamoceratidae sp. A				8		1				
<un-identified>					1					
Helicophidae sp. A				7	1					
Coleoptera										
Adult sp. A							5			
Adult sp. B					12	20	5			
Adult sp. C										
Psephenidae sp. A				7	2	1				
Helminthidae sp. A				5		5	4			
Dytiscidae sp. A				1	5		6			
Helodidae sp. A				1	1					
Hemiptera										
Corixidae sp. B										
Sigara sp. A				2		2	1			
Diptera										
Simuliidae sp. A						4				
Chironomidae sp. A	9			9	4	14	6			19
Tipulidae sp. A	2									
Athericidae sp. A					1					
No. of species	7	2	0	12	13	14	9	0	0	7
No. of individuals	30	5	0	55	39	86	31	0	0	54
Diversity Index (d)	1.94	0.72	0.0	3.08	3.21	3.04	2.88	0.0	0.0	2.19

* Sampling station names listed in Table 1

These high *d*-values are typical for streams draining relatively undisturbed forested catchments. A relatively high *d*-value of 2.88 was also noted for the benthic macroinvertebrate sample from Gorge Creek (Richmond Range State forest), having a catchment that was 83% forested (see Table 1).

Streams draining the low-lying State forests tended to have low community diversity indexes, for example, *d*-values of 1.94 and 2.19 were recorded for Saltwater Creek (Banyabba State forest) and Sandy Creek (Ellangowan/Braemar State forests). These low *d*-values resulted mainly from the low number of species sampled, as species richness is a component in the calculation of the community diversity index.

In those streams having a predominantly sandy substratum, namely Mongogarie Creek (Cherry Tree State forest), Myrtle Creek (Mt. Belmore State forest) and Barrett's Creek (Mt. Marsh State forest), no macroinvertebrates were found in the benthic samples; therefore, the corresponding *d*-values were zero (0.0). The absence of benthic macroinvertebrates was attributable to severe physical conditions (mobile sand substratum, since water quality was good in these streams (Table 4).

The usefulness of the diversity indexes is limited by the once-off sampling program carried out as part of this study. Longer term monitoring is required to assess differences in community diversity in relation to future interactions of forestry operations and water quality (see Section 5).

Murwillumbah Management Area

Community characteristics

The macroinvertebrate communities of streams in the State forests of the MMA were typical of 2nd order streams in forested catchments of the north coast region of New South Wales and southern Queensland and included representatives of widespread faunas in the region.

The macroinvertebrate communities were dominated by the consumer functional group of 'shredders and scrapers' represented by the freshwater shrimp, *Parataya australiensis* (Atyidae), mayfly nymphs (Ephemeroptera) and caddisfly larvae (Trichoptera). A noticeable feature of the streams in the MMA compared to those of the CMA is the predominance of freshwater shrimps in the macroinvertebrate community. The consumer functional group of 'collectors' was well represented by deposit feeders (midge larvae - Diptera, Chironomidae) and filter feeders (e.g., blackfly larvae - Diptera, Simuliidae). Superimposed upon the above functional groups was the 'predator' consumer group which was well represented by dragonfly nymphs (Odonata) and beetle adults and larvae (e.g., Dytiscidae and unidentified beetles).

The trophic status of the riffle communities of benthic macroinvertebrates inhabiting the forest streams relates directly to the large amount of organic matter imported from the forests and streamside vegetation, as described above for macroinvertebrate communities of streams in the CMA.

Species richness

A total of 371 individuals distributed among 27 taxonomic groups (mainly species) of aquatic macroinvertebrate were found in the benthic samples collected from the six streams in the MMA (Table 9). Generally, streams draining the upland State forests had the largest number of species, for example, 14 species in Cooper's Creek (Nullum State forest) and 15 species in Byrill Creek (Mebbin State forest). The substrata of sampling stations established on these two creeks were comprised mainly of cobble (80%) and gravels (10%), which offered structurally diverse habitats.

The lowest number of species (9 species each) was observed in the samples from Cudgera Creek (Mooball State forest) and Wilson's River (Nullum State forest). The substratum at Cudgera Creek was comprised mainly of gravels (50%) and sand (20%), which may account for the reduced number of species found. However, the substratum at Wilson's River was comprised mainly of cobbles (80%) and gravels (10%) and a higher number of species (>9 species) would have been expected. The unexpected lower number of species was probably attributable to sampling variability; hence, the recommendation for additional baseline sampling to be included in the FCNSW's regional monitoring program (see Section 5).

Community diversity index

In general, streams draining the upland State forests had the highest *d*-values, with a range of 2.95 to 3.17. The highest *d*-value of 3.17 was recorded for the macroinvertebrate sample from Cooper's Creek (Nullum State forest). These high *d*-values are typical for streams of good water quality draining relatively undisturbed forested catchments. The lowest *d*-value of 2.11 was recorded for Wollumbin Creek (Wollumbin State forest), the catchment of which was 86% forested and the substratum was dominated by gravels (50%) and sands (20%). Only 9 species of macroinvertebrate were recorded for the sample from Wollumbin Creek, and this also contributed to the low *d*-value.

The usefulness of the diversity indexes is limited by the once-off sampling program carried out as part of this study. Further baseline sampling and monitoring is recommended for inclusion in the FCNSW's regional monitoring program (Section 5).

2.5.4 Fish Fauna

No comprehensive fish surveys have been carried out in streams of the CMA or the MMA, and a species list of native and introduced fish has been constructed from a number of sources:

- University of New England Biology Department, Dr. John Anderson (pers. comm.).

Table 9

Aquatic macroinvertebrate analyses of benthic samples from streams in the Murwillumbah Management Area

Species/Sampling Station	MW20	MW21	MW22	MW23	MW24	MW25
CRUSTACEA:						
Atyidae						
Parataya australiensis	8	13	2	27	11	32
INSECTA:						
Plecoptera						
Illiesoperla australis					4	
Ephemeroptera						
Caenidae						
Tasmanocoenis sp. A		1	3	3	2	
Baetidae sp. A		9		4	3	
Leptoplebidae sp. A	1	3			2	
Odonata						
Corduliidae						
Eusynthemis virgula	1					
Hemicordulia tau	1					
Gomphidae						
Austrogomphus ochraceus	1					
Austrogomphus sp. A					2	
Austrogomphus sp. B					1	
Hemigomphus sp. A		2	2	1		4
Trichoptera						
Leptoceridae sp. A		1		1	3	2
Hydropsychidae						
Hydropsychid sp. A					1	
Cheumatopsyche sp. A		1		8		
<un-identified>		6			1	3
Helicophidae sp. A	1	27				
Coleoptera						
Adult sp. B				5		
Adult sp. C				1		
Psephenidae sp. A	1	24	1	1	33	3
Helminthidae sp. A	9	18	4		10	2
Dytiscidae sp. A		1	2	3	1	1
Gyrinidae sp. A		11	1		6	
Hemiptera						
Veliidae sp. A	2					
Gerridae sp.	2					
Notonectidae sp. A	1					
Diptera						
Simuliidae sp. A			4	3		2
Chironomidae sp. A	4	8	1	2	2	4
No. of species	12	14	9	12	15	9
No. of individuals	32	125	20	59	82	53
Diversity Index (*d*)	2.98	3.17	2.98	2.69	2.95	2.11

* Sampling station names listed in Table 1.

- NSW Fisheries, Eastern Freshwater Fish Research Hatchery (Grafton), Dr. Stuart Rowland and Peter Lynch (pers. comms.)
- Australian Museum (Sydney), Dr John Paxton and Mr. Mark McGrouther (pers. comms.)

A total of 57 species of fish have been recorded by the Australian Museum in the Clarence, Richmond, Brunswick and Tweed river systems (Table 10). Many more species are expected to be present in the river system and, including marine vagrants, the number of fish species is anticipated to be more than twice this figure.

Fish habitats and distribution

Section 2.4.1 divided the river systems of the CMA and MMA into broad morphological types (upland, lowland and estuarine sections), and fish populations most likely to be associated with these broad geographical distributions are described below.

Upland section

The distribution and abundance of fish species inhabiting the upland section is likely to be limited compared to the lowland and estuarine sections. In general the number of fish species in a river system increases from the source to the mouth of the river. This is attributable to highly variable flow regimes, limited number of microhabitats and niches, and lower temperatures of mountain or upland stream reaches. An important aspect of fluctuating discharge is the occasional or annual, drying out of some upland streams, leaving only isolated pools or no water at all, and such conditions limit fish colonisation. During the reconnaissance survey of 22-23rd March 1992, some State forest streams were found to be dry, for example, Filans Creek (Gibberagee State forest) and Six Mile Waterhole Creek (Myrtle State forest), both in the CMA.

Stream temperature is always an obvious ecological factor, and for fish it is an important factor which limits both broad geographical distributions and local occurrences within a single river or stream. For example, introduced trout species in the Clarence and Richmond Rivers favour the cooler temperatures of headstream waters, where low temperatures and high dissolved oxygen levels are required for reproductive success.

In fast-flowing streams draining the upland State forests of both the CMA and MMA, the fish species expected to be present are rainbowfish (Melanotaeniidae), hardyheads (Atherinidae), introduced salmonids (trout), eels (Anguillidae) and various species of river gobies (Gobiidae) and gudgeons (Eleotridae).

The actual distribution and abundance of fish species in streams draining the upland State forests could be assessed by including a fish survey and monitoring component in the post-EIS monitoring program (Section 5).

Table 10

List of fish species recorded by the Australian Museum in the Clarence, Richmond, Tweed and Brunswick river systems

Genus/Species	Common Name	Location
Elasmobranchs (cartilaginous fish):		
SPHYRNIDAE		
Sphyrna lewini	Scalloped hammerhead	RR estuary.
Zygaena spp.	hammerhead	RR mainstream.
Teleosts (Bony fish):		
AMBASSIDAE		
Ambassis agassizi	Glass fish	CR at Lilydale Bridge/Coldstream R.; RR at Eden River.
Ambassis nigripinnis	glassfish	CR mainstream.
Ambassis ramsayi	Ramsey's glassfish	CR mainstream.
ANGUIILIDAE		
Anguilla australis	eel	RR at Webster's Ck. and Cedar Point.
Anguilla reinhardti	glass-eel	CR at Moleville Ck.; BR at Shelley Br.;RR at Cedar Point and Camira; TR headwaters.
ARIIDAE		
Arius australis	fork-tail catfish	CR at Ski Lodge.
Arius graeffei	fork-tail catfish	CR at Seelands.
Netuma thalassina		RR mainstream.
PLOTOSIDAE		
Tandanus tandanus	eel-tail catfish	CR at Coramba and Toolom River; RR at Lismore and Goolmagar Ck.; TR at Crystal Ck.
ATHERINIDAE		
Craterocephalus marjoriae	hardyhead	CR at Deep Ck.
ELEOTRIDAE		
Carassiops compressus	western carp	CR at Harwood Island.
Carassiops klunzingeri	western carp	CR mainstream.
Eleotris australis	Striped gudgeon	CR mainstream.
Eleotris compressus	Empire gudgeon	CR mainstream.
Philypnodon grandiceps	Flathead gudgeon	CR at Lilydale Bridge and Copmanhurst; RR mainstream.
Gobiomorphus australis	Striped gudgeon	CR at Rocky Ck., Moleville Ck, and Mangrove Ck; BR at Mullumbimby and Shelley Br.;RR at Camira, Tuntable Ck.; TR at Crystal Ck and Uki.
Gobiomorphus coxii	Cox's gudgeon	CR at Coramba; RR at Websters Ck.
Hypseleotris compressus	Carp gudgeon	CR atRocky Ck., Moleville Ck., Mangrove Ck., and Woodford Island; BR at Shelley Bridge; TR at Crystal Ck.

Key: CR=Clarence River; RR=Richmond River; TR=Tweed River; and BR=Brunswick River.

Table 10 (Continued)

List of fish species recorded by the Australian Museum in the Clarence, Richmond, Tweed and Brunswick river systems

Genus/Species	Common Name	Location
ELEOTRIDAE (continued)		
Hypseleotris galii	Firetail gudgeon	CR at Coldstream R., Flaggy Ck., Rocky Ck. Saltwater Ck., and Poperaperin Ck.; RR at Camira Ck. and Eden R.;BR at Shelley Bridge.
Hypseleotris klunzingeri		Koreelah Ck.
Mogurnda adspersa	Purple-spotted gudgeon	CR mainstream.
Mogurnda mogurnda	N. Trout gudgeon	CR mainstream.
Mogurnda australis	gudgeon	CR at Coldstream River.
GALAXIIDAE		
Galaxias olidus	Marbled galaxia	CR at Ann River; Little Nymboida R.,Ulong R.
and		Wallaby Ck.; RR mainstream.
POECILIDAE		
Gambusia affinus	Mosquito fish	CR at Deep Creek;Flaggy Ck. and Moleville Ck.; BR estuary.
MUGILIDAE		
Liza argentea	mullet	CR at Copmanhurst.
Myxus elongatus	mullet	CR at Copmanhurst.
Trachystoma petardi	mullet	CR at Lilydale Bridge; BR at Shelley Bridge. RR at Tuntable Ck.
Mugil sp. A	mullet	RR mainstream.
Mugilogobius paludis	mullet	BR estuary.
LUTJANIDAE		
Lutjanus superbus	snapper	CR mainstream (70 km upstream).
PERCICHTHYIDAE		
Maccullochella novemaculeata	Australian bass	CR upstream of Mann River.
Maccullochella ikei	Eastern fresh-water cod	CR at Nymboida and Mann Rivers.
Maccullochella macquariensis	Trout cod	RR mainstream and RR at Wilson's Ck.
Madigania unicolor	Spangled perch	RR at Toonumbar Dam.
Percalates colonorum		BR at Shelley Bridge.
Percalates novaemaculatus	Australian bass	RR at Rileys Hill.
Oligorus macquariensis		RR mainstream.
KUHLIIDAE		
Nannoperca oxleyana	Oxleyan pygmy perch	RR at Cedar Point.

Key: CR=Clarence River; RR=Richmond River; TR=Tweed River; and BR=Brunswick River.

Table 10 (Continued)

List of fish species recorded by the Australian Museum in the Clarence, Richmond, Tweed and Brunswick river systems

Genus/Species	Common Name	Location
MELANOTAENIIDAE		
Melanotaenia fluviatilis	rainbowfish	CR at Lilydale Bridge; RR mainstream.
Melanotaenia nigrans	rainbowfish	CR at Coramba.
Melanotaenia splendida	rainbowfish	CR at Deep Ck., Mangrove Ck., and Poperaperin Ck.; RR at Tuntable Ck.;TR at Crystal Ck.
Nematocentrus spp.	rainbowfish	CR at Coldstream R., Flaggy Ck. and Rocky Ck.; RR at Eden R.
Pseudomugil signifer	Pacific blue-eye	CR at Copmanhurst and Coldstream R.; RR at Tuntable Ck.; BR at Shelley Bridge; and TR at Uki.
Rhadinocentrus ornatus	Ornate rainbowfish	CR at Mangrove Ck.
CLUPEIDAE		
Potamalosa richmondia	freshwater herring	CR at Lilydale Br. and Mangrove Ck.
Clupea sundaica	herring	RR mainstream.
SYGNATHIDAE		
Hippichthys heptagonus	Pipefish	CR at Khoolkhan Power Station; RR at Tuckurimba and Cedar Point.
RETROPINNIDAE		
Retropinna semoni	Tasmanian smelt	CR at Deep Ck., Koreelah Ck., Mangrove Ck. and Toolom R.; BR at Shelley Bridge; RR at Tuntable Ck., and Big Rocky Ck.; and TR at Crusytal Ck.
ALBULIDAE:		
Albula vulpes	Bone fish	CR at Carr's Creek.
SCORPAENIDAE		
Notesthes robusta	Bulltrout	RR at Cedar Point.
GOBIIDAE		
Parvigobius immeritus		RR at Coraki.
PATAECIDAE		
Pataecus fronto	Red indian fish	RR mainstream.
CENTROPOMIDAE		
Priopis agassizi		RR at Cedar Point and Kyogle.
PETROMYZONTIDAE		
Mordacia mordax	Lamprey	RR mainstream

Key: CR=Clarence River; RR=Richmond River; TR=Tweed River; and BR=Brunswick River.

Lowland section

The fish of the lowland section are more diverse than in the upland section because of the increased number of microhabitats and food resources. The endangered eastern freshwater cod *(Maccullochella ikei)* maintains populations along the lowland sections of the Clarence River, Nymboida River and Mann River.

Small tributaries of the lowland sections of the main rivers of the CMA and MMA harbour populations of small fish species or the juvenile stages of larger fish species. Examples are gudgeons (Eleotridae), hardyheads, (Atherinidae), rainbowfish and blue-eyes (Melanotaeniidae), glassfish (Ambassidae). Populations of larger mainstream fish of the Richmond and Tweed River lowland section include Australian bass *(Macquaria novemaculeata)*, fork-tailed catfish (Ariidae), eel-tailed catfish or tandans (Plotosidae), glass-eels (Anguillidae), snapper (*Lutjanus superbus*) and mullet (Mugilidae).

Estuarine section

The estuarine section comprises the tidal reaches of the Richmond, Tweed and Brunswick Rivers and coastal streams draining the Coast Range. The fish fauna of this section are characterised by the presence of true freshwater species, estuarine species, and a significant number of visiting marine species. Some marine species invade the lower parts of the rivers and remain for some time to breed or grow in the fresh or brackish waters. A full list of estuarine and marine species has not yet been completed for the main rivers of the CMA and MMA.

Fish community diversity

A total of 38 species of fish have been recorded by the Australian Museum (Table 10) for the Clarence River, 30 species in the Richmond River, 9 species in the Brunswick River and 7 species in the Tweed River. Obviously, these totals are far less than the expected numbers of fish species in each river. However, the collated list of fish species and information on their breeding and feeding ecology and migratory behaviour is adequate to allow an assessment of the impacts of forestry operations on their aquatic habitats and populations (see Section 4). The species list could be expanded by the fish sampling component recommended for inclusion in the FCNSW's regional monitoring program (Section 5). Additional information on fish species and distributions may be gained from a comprehensive literature review and interviews with tertiary and research institutions in NSW and Queensland.

Conservation status of fish fauna

The conservation status of Australian freshwater fish was examined by Pollard *et al.* (1990). In the Northern Rivers region of New South Wales, the eastern freshwater cod (*Maccullochella ikei*), found principally in the Clarence and Richmond Rivers, has an endangered species classification. The trout cod (*Maccullochella macquariensis*) found in the Richmond River system also has an endangered species classification.

The eastern freshwater cod requires a variety of habitats during its life cycle, including clear water, and small to large, deep waterholes separated by gravel beds and abundant rock cover.

In an effort to conserve the Eastern freshwater cod there is a total prohibition on its capture, although poaching takes place, and NSW Fisheries operate a re-stocking program for the Clarence and Richmond Rivers (Peter Lynch, NSW Fisheries, pers. comm.).

2.5.5 Water-associated Fauna

A full species list and the distribution of vertebrate fauna associated with permanent and temporary water bodies within the CMA and MMA are given in Austeco (1993). This section of the report identifies those vertebrate species that either live in or at the edge of permanent stream systems within the CMA and MMA, and which depend on either aquatic food resources or stream habitats for part of their life cycle.

Table 11 gives a species list of water-associated fauna either sighted or expected to be present along the stream systems of the Casino District. Sources of data are Austeco (1993, this EIS), FCNSW (1984) and FCNSW (1987). Codes used for habitats, reproductive sites, observation status, and conservation status in Table 11 are described in Table 12.

Mammals

A few species of placental mammals that may occur in the CMA and MMA and be closely associated with streams include the water rat *(Hydromys chrysogester)* and swamp rat *(Rattus lutreolus)*. Water and swamp rats do not depend entirely on aquatic food resources and streamside vegetation provides alternative supplies of plant and invertebrate foods.

Water-associated egg-laying mammal species are represented by platypuses *(Ornithorhynchus anatinus)*, which depend to a large extent on stream-bottom macroinvertebrates as a food source and can therefore be affected by primary impacts on these food resources.

Degradation of in-stream habitats by sedimentation can also affect the distribution and presence of platypuses in the affected river reaches.

Amphibians and reptiles

Approximately 36 species of amphibian (Families, Myobatrachidae and Hyalidae) and 6 species of reptile (Families: Agamidae, Chelidae, Scincidae and Elapidae) were either sighted or expected to be present in the study areas covering the combined Casino and Murwillumbah Management Areas.

Table 11

List of faunal species associated with aquatic habitats in the Casino and Murwillumbah Management Areas. (After Austeco 1992, this EIS)

Sub-class/Order Family/Species	Common name	Habitat/ reproductive site	Observation status #CMA/MMA	Conservation status
MAMMALS:				
Prototheria (Egg-laying mammals)				
Ornithorhynchidae				
Ornithorhynchus anatinus	Platypus		2/2	
Eutheria (Placental mammals)				
Rodentia (rodents)				
Muridae				
Hydromys chrysogester	Water rat		2/2	
Rattus lutreolus	Swamp rat		2/2	
REPTILES				
Agamidae (Dragon lizards)				
Physignathus lesueurii	Eastern water dragon	12,16	1/1	
Elapidae (Elapid snakes)				
Hemiaspis signata	Marsh snake	1,2,3,9,12	1/1	
Chelidae				
Chelodoina longicollis	Long-necked turtle	9,12,16,17	1/2	
Elseya latisternum	Saw-shelled turtle	12,16,17	2/2	
Emydura signata	Short-necked turtle	12,16,17	2/1	
Scincidae				
Eulamprus quoyii	Eastern water skink	2,3,4,12,16	1/1	
AMPHIBIANS				
Myobatrachidae				
Adelotus brevis	Tusked frog	1,2,6/5	1/1	
Lechriodus fletcheri	Fletcher's frog	1,2/1,5	1/1	
Limnodynastes ornatus	Ornate burrowing frog	1,2,3,4/4,5	1/2	
Limnodynastes dumerilli	Eastern Banjo frog	9,16/1,2,3	2/1	
Limnodynastes peronii	Brown-striped frog	9,16,17/1,2,3	1/1	
Limnodynastes tasmaniensis	Spotted grass frog	20/1,2,3,4	1/2	
Mixophyes balbus	Stuttering frog	2/1	2/1	VR
Mixophyes fasciolatus	Great barred frog	1,2/1	1/1	
Mixophyes iteratus	Giant barred frog	1,2/1	1/1	VR
Platyplectron terraereginae	Northern Banjo frog	1,2,3,4/1,2,3	1/2	
Pseudophryne bibronii	Brown toadlet	2,3,6/4,5	1/2	
Pseudophryne coriacea	Red-backed toadlet	2,3/5	1/1	
Crinia signifera	Common Eastern froglet	20/1,2,3,4,5	1/2	
Crinia parinsignifera	Froglet	20/2,3,4	1/2	
Crinia tinnula	Wallum froglet	9/3	2/2	VR
Uperoleia laevigata	Red-groined toadlet	2,3,4	1/2	

CMA/MMA = Casino/Murwillumbah Management Areas

Table 11 (Continued)

List of faunal species associated with aquatic habitats in the Casino and Murwillumbah Management Areas. (After Austeco 1992, this EIS)

Sub-class/Order Family/Species	Common name	Habitat/ reproductive site	Observation status #CMA/MMA	Conservation status
AMPHIBIANS (continued):				
Hyalidae (Tree frogs)				
Litoria aurea		9,16,17/1,2,3	2/2	T
Litoria brevipalmata	Green-thighed frog	2/4	2/1	VR
Litoria caerulea	Green tree frog	20/4	1/1	
Litoria chloris	Red-eyed tree frog	1,2/1	1/1	
Litoria fallax	Eastern dwarf tree frog	9,16/1,2,3	1/2	
Litoria gracilenta	Dainty green tree frog	20/1,4,5	1/2	
Litoria latopalmata		2,3,4,12,15/2,3,4	1/1	
Litoria nasuta	Rocket frog	2,3,7,9,15/3,4	1/1	
Litoria dentata	Bleating tree frog	9/3,4	1/2	
Litoria lesueurii	Lesueur's frog	20/1,2,3,4	1/1	
Litoria olongburensis		9,16/1,3	1/2	
Litoria peronii	Peron's tree frog	20/1,2,3,4	1/2	
Litoria pearsoniana		1,2,12/1,3	1/1	
Litoria revelata		9/3,4	2/2	
Litoria subglandulosa		2,12/1,2,3,4	2/2	VR
Litoria phyllochroa	Leaf green tree frog	9,16,12/1,2	2/2	
Litoria rubella	Desert tree frog	20/1,3,4		
Litoria tyleri		20/1,2,3,4	1/2	
Litoria verreauxii		2,3,6,9,12/1,2,3	2/1	
Litoria barringtonensis	Mountain stream frog	?/?	-/1	

CMA/MMA = Casino/Murwillumbah Management Areas

Table 12

Codes for habitat, reproductive sites, and the observation and conservation statuses of fauna associated with aquatic habitats

Habitat:

1	Rainforest	2	Wet sclerophyll	3	Dry Sclerophyll	4	Woodland
5	Shrubland	6	Grassland	7	Littoral forest	8	Heath
9	Swamp	10	Mangrove	11	Coastal scrub	12	Riparian
13	Arid woodland	14	Urban	15	Forest-grassland ecotone		
16	Streamlines	17	Aquatic	20	Wide variety of habitats		

Observation status:

1 Definite sighting

2 Not sighted, but expected to be present in CMA or MMA.

**Conservation Status*

VR Vulnerable and rare

T Threatened

* *NPWS Act (as amended 1992) Schedule 12*

The results of the terrestrial fauna carried out as part of the present study (Austeco 1993) indicated the actual presence of 25 species of amphibian and 3 species of reptile in the CMA, and 17 species of amphibian and 3 species of reptile in the MMA.

Most of the frog species recorded in the CMA and MMA occur widely throughout New South Wales and southern Queensland. Several diverse frog assemblages were found in the study area in vegetation along the channels of permanent water courses or swamp areas associated with the streams, especially in the low-lying areas of the coastal State forests.

Many of the above water-associated fauna, e.g., frog species, have part of their life-cycle intimately associated with streams and swamps, and the aquatic stages such as tadpoles may be susceptible to adverse effects arising from forestry operations.

Conservation status

Three species of myabatrachid frog are classified as vulnerable and rare, under Schedule 12 of the *National Parks and Wildlife Act* (as amended in 1992). These are the Giant-barred frog *(Mixophyes iteratus)*,the Wallum froglet (*Crinia tinnula*) and another southern frog species *(Mixophyes balbus)*. Three species of tree frog (Hyalidae) have a conservation classification: a species of tree frog *(Litoria aurea)* having a threatened species classification, and two species having a vulnerable and rare classification, namely, the green-thighed frog (*Litoria brevipalmata*) and another tree frog species (*Litoria subglandulosa*).

2.5.6 Water Supplies

Water supplies in the CMA and MMA are described below.

Casino Management Area

There are no major dams for water supplies having catchments within the CMA, and there are no significant irrigation, agricultural or other uses of water flowing from the Area.

Murwillumbah Management Area

There are four existing water supply systems which depend to various degrees on contributions from catchments within the MMA and these are described in Table 13. The City of Lismore and the towns of Byron Bay, Brunswick Heads, and Evans Head and surrounding districts draw their water from the Rocky Creek Dam. The water supply is filtered and chlorinated. Periodic problems are encountered with algae, but these are not related to catchment problems. No significant problems associated with soils or suspended sediments have been noted for previous forestry operations (Cornish 1980a).

The catchment of the Rocky Creek Dam is of particular significance because it falls almost entirely (95%) within the MMA. The value of protecting the Rocky Creek

Dam catchment has been given formal recognition by appropriate P.M.P. designations and less formally by appropriate constraints on forestry activities.

The whole of Rocky Creek catchment has been designated under various P.M.P. Special Emphasis Classifications, with the major portion designated P.M.P. 1.1.5 Special Emphasis Catchment Protection. Other prescriptions of importance are:

- Provision of a 40 m buffer strip around the foreshore of the Rocky Creek Reservoir and along both sides of Rocky and Little Rocky Creeks designated as P.M.P. 1.1.7 Special Emphasis Flora and Fauna Protection. Harvesting has been excluded from these areas so as to maintain or encourage a mature forest structure as well as protection reservoir water quality.

- An area of Subtropical Rainforest adjacent to the Big Scrub Flora Reserve has been designated as P.M.P. 1.3 Preserved Natural Forest. Harvesting has been excluded from this area so as to protect the rainforest and consequently also protects reservoir water quality.

- The balance of rainforest types are designated as P.M.P. 1.1.7 Special Emphasis Flora and Fauna Protection, and therefore considerably protected from disturbance and consequently also protecting reservoir water quality.

Under the new SEMGL, the 40-m vegetation strip around the foreshore may be extended to 100 m.

On the remainder of the catchment area particular measures in addition to Standard Erosion Mitigation Guidelines for Logging (SEMGL) in N.S.W. are seen to be necessary to protect the catchment values of the area.

No specific measures additional to the SEMGL are in place to protect other catchment water supplies.

Table 13

Water supplies within the Murwillumbah Management Area

Water Supply	State forests in catchment	Per cent of water supply catchment in MMA
Rocky Creek Reservoir	Part Whian Whian	95
Wilson's River dam	Part Nullum	30
Tweed & Oxley Rivers	Part Nullum	15
	Wollumbin and Mebbin	
Clarrie Hall dam	Part of Nullum	10

[After FCNSW (1984)]

3. Literature Review

Different forest management practices impose a variety of effects on the physical, chemical and biological character of catchment drainage. The potential environmental effects and interaction of forest management on catchment hydrology, water quality, aquatic biology and water supplies are reviewed below.

3.1 Interaction of Forest Management and Hydrology

Catchment effects of timber harvesting and silvicultural treatments (planting, thinning, burning, mechanical site preparation, and application of chemicals) on streams are complex. Timber harvesting may change the distribution of precipitation that reaches the ground (and evaporation rate from the ground), the amount that is intercepted or evaporated by foliage, as well as the amount that can be stored in the soil. These hydrological properties, as well as the extent of road and surface drainage networks and the physical structure of the soil, govern the rate and pathways of the movement of water to stream channels.

Since the results from hydrological studies are highly site specific, it may be inappropriate to make quantitative comparisons or extrapolate to analogous forested catchments. Nonetheless, general principles have been established on the various impacts of forest management activities on catchment water yield and stream response.

The principal influences of forest management on catchment hydrology relating to runoff and water yield, and sediment production are reviewed below.

3.1.1 Runoff and Water Yield

Forestry operations such as road building, harvesting, log dump construction, and burning can affect watershed hydrology and stream flow much more than can other management activities such as planting and thinning. However, depending on their nature and scope, harvesting and thinning operations can have significant local impacts on water yields, both in the short and long term. Harvested areas tend to contain wetter soils than unlogged areas during periods of evapotranspiration and hence higher groundwater levels and more potential for runoff. Road systems, snig tracks, and log dumps also tend to accelerate slope runoff and concentrate drainage below them.

It has been demonstrated in numerous studies worldwide, that harvesting timber from forested catchments generally increases stream flow and increases catchment water yield (Greacen & Sands 1980; Bosch & Hewlett 1982; Troendle & King 1987; Smith 1991). Bosch & Hewlett (1982) summarised 94 catchment experiments and concluded that an average increase in stream flow yield of 40 mm/yr per 10% cover reduction could be expected from large-scale harvesting of pine and eucalypt stands. A similar study in South Africa showed an increase in stream flow of approximately 50 mm/yr for every 10% reduction in the cover of pine forest and eucalyptus stands (Smith 1991).

There has been some debate concerning the effects of timber harvesting on peak flows and stormflows in forest streams. Changes are usually so small that they will have negligible effect on the catchments. However, significant increases in low stream flow volume following timber harvesting have been found by researchers in North Carolina studying mountain watersheds (Douglass & Swank 1975; Lieberman & Hoover 1951). By measuring the water balance in forested and logged watersheds, they showed that harvesting operations can reduce evapotranspiration and increase groundwater storage and base flow.

The validity of using overseas research may be limited when considering Australian conditions. There are no research data on hydrology in the CMA and MMA State forests. However, a few studies have been carried out in Australia and these are reviewed below.

Cornish (1991) reported on research carried out by FCNSW on the Karuah hydrology research catchments (Newcastle Region), which has a similar hydrological and topographical setting as some of the State forest catchments in the CMA and MMA. A significant increase in runoff was observed during the first year following harvesting, which declined over the next 6 years in one catchment to a value less than pre-harvesting levels. Higher water demands from the regenerating forest compared to original forest to the lower pre-harvesting level.

The Melbourne Metropolitan Water Board is currently conducting a long-term program of hydrological research in the North Maroondah experimental area. Preliminary indications are that a 50% strip thinning of a forest led to an increase in runoff and stream flow (Benyon 1992). Runoff increased by 190 mm per annum and the annual water yield increased by 2.5 megalitres per hectare of forest available for harvesting.

Ruprecht *et al.* (1991) studied the effect of thinning in a small catchment in southwest Western Australia on hydrology. They found that intensive thinning treatment which reduced crown cover from 60 to 14% resulted in an increase in stream flow of approximately 20% of annual rainfall (260 mm annual average) after 3 years, compared with a stream flow yield of 6% of annual rainfall before thinning. The cause of additional stream flow following thinning is generally attributed to the reduction in evapotranspiration brought about by a reduction in overstorey (Stoneman & Schofield 1989).

In Queensland tropical rainforests, Gilmour *et al.* (1982) found little detectable hydrological change in selectively-logged areas. However, Cassells *et al.* (1982) recommended that strips of undisturbed vegetation be retained adjacent to streams in catchments (<100 ha.) that are exposed to high discharge levels. This has been confirmed by US studies in which Riggs (1965) noted that clearing of land along stream channels seems to have a greater effect on discharge than clearing over the catchment generally. The FCNSW retain filter strips of forest vegetation along streams having a catchment area in excess of 30 ha.

Fires

Fuel reduction burning was found to double localised surface runoff in burnt areas within a mixed species eucalypt forest in Victoria (Ronan 1986); but, negligible effects on water quantity were observed at the catchment scale. In general, due to their small areal extent, slash and other fuel reduction burnings do not significantly increase water yield in a catchment. This is largely due to the rapid growth of post-burn vegetation, which increases transpiration and interception losses. On the other hand, large-scale bush fires are likely to significantly increase water yield from a burned catchment.

3.1.2 Surface Erosion and Sediment Production

A discussion of the interaction of forest management activities on soil erosion is given in Supporting Document 7. However, this section also highlights some specific surface erosion problem areas that are the sources of sediments transported in overland flow or directly to the natural drainage.

Sources of sediments from surface erosion

Excessive erosion resulting from harvesting and forest road-construction has long been a concern to forest managers and the general public. A number of studies has revealed that most erosion occurring on timber harvesting areas was due to mass movements found on a small fraction of the harvest sites. Identification of these areas was the key to reducing erosion from logged areas and forest roads. Durgin *et al.* (1988) suggested that site conditions were more important than forest management practices in determining the erosional consequences of logging or road construction.

The potential for surface erosion is directly related to the amount of bare compacted soil exposed to rainfall and runoff. Hence, road surfaces, landings, snig tracks, ditches and disturbed logged areas can contribute large quantities of fine sediments to stream channels. Not all hillslope sediments reach stream channels, but roads and associated ditches form important pathways. For example, gravel-surfaced logging roads can increase sediment production by 40% when they are heavily used by trucks (Chamberlin 1991).

Mass movement of soil including all categories of slope failure such as slumps, creep, earthflow and debris slides, is a predominant erosional process in steep high-rainfall forest lands. The frequency of mass erosion events in forested catchments is linked to forest management practices in the catchments. Although most mass movements are associated with roads and their drainage systems, some can originate on open slopes after logging has raised soil water tables and decreased root strengths. However, mass movement is not a principal erosion process in NSW forests (Cornish, pers. comm.).

Sediment production

In a North American study, Grant (1991) considered that timber harvesting operations primarily affected sediment production and transport by changing the magnitude and frequency of mass erosion events rather than by directly affecting the supply of sediment to the natural drainage system. Grant (*op. cit.*) found that, over a 20-year period, total sediment production from a 100% clear-cut watershed without roads was about twice that of an undisturbed forested control watershed.

Sediments discharged to water courses draining forested lands can be increased by forestry operations, especially in upland areas. Published rates of erosion range from 214 to 1300 kg/ha per year (Moffat 1991), though the higher rates reflect episodes of accelerated erosion during and after ground preparation or harvesting, and background rates are usually considerably less. A scan of the scientific literature did not reveal equivalent erosions rates for Australian forests subjected to harvesting operations.

Log dumps

Log landing areas for the temporary storage of timber comprise exposed and compacted soil. Surface erosion from these log landing areas also contributes minor sediment loading of the natural drainage.

Compaction

Forest soils may be compacted by grazing animals and by the roots of trees themselves, but some degradation is caused by vehicles used in mechanised forest operations (Greacen & Sands 1980), especially when timber is extracted during thinning or selective logging in wet conditions. In hardwood forest operations, compaction occurs mainly on log dumps, snig tracks and roads.

Roads

Roads can affect streams directly by accelerating erosion and sediment loadings, by altering channel morphology, and by changing the runoff characteristics of catchments. Construction of a road network can lead to greatly accelerated erosion rates in a catchment (Haupt 1959; Swanson & Dyrness 1975).

Studies of forest roads in upland areas have shown that most sediment reaching stream channels is mobilised by surface erosion on access roads, contour tracks, and log landings (Megahan & Kidd 1972; Fahey & Coker 1992). However, road-related surface erosion is regarded as more persistent and widespread. Roading can trigger mass movement in the form of slumps and slides from over-steepened cut banks and unstable fill slopes.

Channel disturbance and direct additions of soils during road construction account for most of the increased sediment yield, plus some surface erosion of fill slopes immediately adjacent to road culverts. Increased sedimentation in streams following road construction can be dramatic and long-lasting. The sediment contribution per

unit area from roads is often much greater than that from all other forest management activities combined, including log snigging and yarding (Gibbons & Salo 1973). In general, cutting and snigging operations contribute little to sediment production.

Fahey & Coker (1992) studied fine sediment generation from upland forest roads in New Zealand. Fine sediment production values averaged 2.3 kg/m^2/yr, reaching a maximum of 7 kg/m^2/yr from fresh side-cast fill were typical for forest roads in hilly terrain and an annual rainfall of 1000 mm. A low, but conservative value of 2 kg/m^2/yr has been adopted in the present study and takes account of the FCNSW adoption of Standard Erosion Mitigation Conditions, road alignments following hill ridge lines, and the retention of buffer strips of natural vegetation along stream lines. O'Shaughnessy & Jaysuriya (1987) determined the same rate of sediment generation (20,000 kg/ha/yr = 2 kg/m^2/yr) for road construction in Melbourne Metropolitan Board of Works catchments.

Fires

After bushfires, ground surfaces are unprotected and susceptible to erosion. Good (1973) made a preliminary assessment of fires in the Kosciusko National Park and reported significant local increases in erosion but overall, only minor erosion was evident. Post-fire erosion is greatly dependent on vegetation type and it's rate of recovery, and also upon the initial post-fire rainfall pattern.

Blong *et al.* (1981) investigated the sediment yield from small runoff plots following a bushfire near Narrabeen Lagoon, NSW. Very high sediment losses of 2.5 to 8.0 t/ha/yr occurred despite very low rainfall. They estimated that with normal rainfall, losses could have been as high as 20 t/ha/yr.

Fires brought about by fuel reduction burning by virtue of their small areal extent and degree of control generally do not lead to any significant erosion.

From the above studies it appears that road construction, harvesting operations and bushfires can increase the sediment yield from disturbed forested catchments. However, after initial high sediment yields from road construction and longer term elevated sediment yields from logging operations, sediment yields are expected to return to pre-disturbance levels within a few years following cessation of forestry operations. As long as harvesting operations are current in a forested catchment, elevated sediment yields can be expected.

3.1.3 Sediment Transport Capacity

Most streams draining undisturbed forested catchments carry natural sediment loads, and most concern with forestry operations is substantial changes in the magnitude, timing, or duration of sediment transport.

Sediment transport in streams involves the detachment and entrainment of sediment particles, their transport, and their deposition. The process repeats whenever stream flow velocities are elevated enough to move the stream's available material.

Forestry operations directly affect these processes when they increase the supply of sediment and when they alter the peak flow or the frequency of high flows.

When forestry-derived sediments enter the natural drainage, their effects on the aquatic environment are dependent upon the sediment carrying capacity of the streams. When the sediment carrying capacity of streams draining disturbed forest catchments is exceeded, deposition of coarse material results and is often characterised by highly-localised but temporary sedimentation of stream beds. Winterbourn & Rounick (1985) showed that streams on the West Coast of South Island (New Zealand) suffered a severe short-term impact from logging activities, but that subsequent storms removed almost all of the deposits.

As the sediment carrying capacity of a stream is proportional to the cube of its velocity, fast flowing upland streams can carry large loads of sediments to be deposited in downstream lower-gradient reaches.

3.2 Interaction of Forest Management and Water Quality

Relatively few scientific studies of the effects of forestry activities on stream water quality in Australia have been published. Thus the full nature and extent of water quality changes to this form of disturbance cannot yet be determined let alone predicted with any degree of certainty. However, tentative interpretation of the studies that have been carried out is possible.

The deterioration in the water quality of NSW streams following harvesting operations has been demonstrated by Cornish (1980a; 1980b; 1990; and 1991). The duration of harvesting-induced changes in stream water quality generally depends on the magnitude and duration of harvesting operations. Stream-water response is generally extended for, say a three-year harvesting operation, due to varying inputs in time and space from distinct chemically evolving contributing areas within a forest catchment. When logging takes place during a more intensive (in time) or extensive (in area) harvesting policy, water quality effects can be more pronounced.

The principal water quality variables that may be influenced by forestry operations are temperature, dissolved oxygen, suspended sediment and nutrients.

3.2.1 Water Temperature

The principal factors influencing stream water temperatures are seasonality and flow rate. Air temperature is the primary factor influencing the water temperature of small forest streams. However, shading afforded by riparian vegetation generally helps maintain cool stream temperature in summer and, to a lesser degree, insulate the stream from heat loss in winter. Large-scale harvesting of with significant reductions in crown cover is known to cause elevations in stream temperatures; however, selective logging or clear-felling with the retention of filter strips of vegetation along streamlines tends to have an insignificant effect (Burns 1972).

In a NSW water quality study by Cornish (1980b) temperatures of streams draining unlogged and logged hardwood forests east of Bega were compared over a 12-month

period. Most of the streams draining logged catchments had higher mean annual temperatures (+1 to 2°C) than in the stream draining the unlogged catchment. However, temperature differences narrowed following the shading effect of forest regrowth. Overseas studies indicate that temperature changes of this magnitude generally have a minimal impact on stream fauna (Lantz 1971).

3.2.2 Dissolved Oxygen

Forest harvesting and silviculture can reduce dissolved oxygen regimes in forest streams through accumulations of organic debris on and in the stream bed, and by in-stream sedimentation. The high chemical and biological oxygen demands of accumulated debris and associated bacteria can reduce dissolved oxygen concentrations in the stream bed interstices and overlying water until the bottom material is scoured by elevated flows. Streams draining low-lying coastal forests are more susceptible to changes in dissolved oxygen than upland streams. The latter are constantly re-aerated by turbulent entrainment of atmospheric oxygen, and other re-oxygenation processes.

Clogging of surface gravels by fine inorganic sediments can restrict inter-gravel water flow and lower dissolved oxygen concentrations. However, this problem only occurs when large or persistent volumes of sediment emanate from active road and snig track systems, mass soil movements, and bank slumps (Chamberlin *et al.* 1991).

During extremely low flows, DO concentrations decline in streams and turbulent exchange of dissolved gases with air also decrease. In the warmer months, high temperatures both accelerate the respiration activities of fish and macroinvertebrates in streams and also lower the solubility of oxygen. Forestry operations that accelerate the entry of biodegradable particulate and soluble organic matter to streams that impose significant oxygen demands will exacerbate the normal stresses that low flows place on fish and macroinvertebrate life.

3.2.3 Total Suspended Sediments

Timber harvesting and road construction in mountainous terrain are frequently cited as major contributors to elevated total suspended sediment (TSS) concentrations and turbidity in receiving stream systems. Increased TSS concentrations and turbidity have potentially adverse effects on fisheries, aquatic invertebrates and vertebrates, as well as causing deteriorations in downstream water quality, reservoir storage and recreational values (Cornish 1980b).

Harvesting operations can influence suspended sediment concentrations in a variety of ways, all related to the erosion and sediment production processes. Most forest streams carry natural sediment loads, and most concern with forest management activities is substantial changes in the magnitude, timing, or duration of sediment transport. Poorly designed roads and snig track systems are persistent sources of sediment, as are open slopes whose soils have been exposed by mass movements or scarification. However, some studies have shown that careful, well-planned forest harvesting can take place without appreciable sediment production (Packer 1967), whereas others have documented very high sediment levels (Reinhart *et al.* 1963) as a result of unplanned activity.

Few studies have identified the component of suspended stream sediments originating from harvesting activity alone (without road construction or road use influence).

In North American studies, Farrell & Novotny (1985) examined water turbidity in streams draining harvested and unlogged catchments and showed that the maximum desirable level of 5 NTU (Nephelometric Turbidity Units) was exceeded in 9% of water samples from an undisturbed catchment compared to 24% of samples from harvested catchments. Major sources of sediments were identified as arising from compacted areas such as roads, snig tracks and log landings.

TSS production and turbidity following forest management activities have been documented for small watersheds in NSW (Cornish 1980a and 1980b; Rieger *et al.* 1979; and Burgess *et al.* 1981) and Victoria (Kriek and O'Shaughnessy 1975). These studies are reviewed below.

Cornish (1980a) studied the effect of hardwood logging on stream turbidity values in Rocky Creek, near Lismore (NSW), and compared them with an unlogged reference catchment (Little Rocky Creek). The turbidity means between the two creeks were not significantly different, but the maximum values were greater in Rocky Creek. He observed that logging activities did affect turbidity values in Rocky Creek during wet periods, but that no significant differences were found on a significant proportion of the sampling dates. Elevated turbidities were found during logging when machinery crossed creek beds.

Cornish (1980b) also studied the effect of logging operations, both past and present, on stream turbidity levels in coastal hardwood forests at Bega on the south coast of NSW. Turbidity range values in three control streams draining unlogged eucalyptus forest catchments were 0 to 43 NTU, 0.2 to 8.9 NTU and 0.2 to 10.1 NTU. This was compared to a range of 0 to 60 NTU in a stream draining a forest logged at a rate of 5% per annum and to a range of 1.3 to 35.1 NTU in a stream draining a forest logged at a rate of 10% per annum. He concluded that the effect of logging operations on stream turbidity was slight, and that the aquatic environment did not appear to have been adversely affected or degraded.

Cornish (1991) reported the findings of the Karuah hydrology research catchments and concluded that the primary factor influencing stream turbidity was the extent of soil disturbance in drainage lines by the operation of machinery.

Kriek and O'Shaughnessy (1975) have reported the impact of roading and logging in two catchments in the Coranderrk experiment in Victoria, where a mature forest of *Eucalyptus regnans* was subjected to harvesting of 50% of the timber stand. Double mass plots showed an initial impact due to roading with increases in sediment loads which returned to pre-disturbance levels in approximately 12 months. A further disturbance accompanied timber harvesting, with a trend towards pre-treatment sediment loads after 2 years. Langford *et al.* (1982) described the same catchments and reported that TSS concentrations in Blue Jacket Creek increased by 50% from an average of 14 mg/L to 21 mg/L at the time of road construction, with no recovery in concentrations in the post-treatment period. In addition, there was a 25% increase

in stream flow, further increasing sediment loads in the creek. In Pincanny Creek there was a temporary increase in TSS concentration followed by a rapid recovery to pre-treatment levels. The difference was attributable to differences in road drainage, with Blue Jacket Creek having longer and steeper sections of road draining towards the stream.

In the Eden area of NSW, the impact of heavy logging in a dry sclerophyll catchment was examined by Rieger *et al.* (1979) and Burgess *et al.* (1981). Sediment loads increased up to 150% following roading and the commencement of logging, with recovery to pre-treatment levels within 12 months. Most of the sediment load was explained by road construction, and sediment loads tended to decrease as logging progressed. However, the interpretation of results in this study was complicated by the occurrence of extreme storm events immediately after road construction.

Olive and Walker (1982) reviewed overseas and Australian literature and concluded that increases in sediment yield from Australian forests were not as great as those reported in North America, and that they persisted for a shorter time.

From the above studies, it is clear that road construction and harvesting operations can result in significant increases in stream suspended sediment loads. The major sediment sources in Australian studies appear to be from roading and snig tracks and from soil disturbance in drainage lines. Because suspended sediment concentrations in streams draining undisturbed forested catchments are generally low, road construction and harvesting operations are expected to have a major bearing on water quality.

Fires

After a major fire, the ground surface is unprotected by vegetation and is more susceptible to erosion with consequent sediment loading of streams. Brown (1972) described the water quality effects of a large-scale fire in the Yarrangobilly River and Wallace's Creek in the Snowy Mountains region. Maximum TSS concentrations after the fire were 112,000 mg/L and 143,000 mg/L for Yarrangobilly River and Wallace's Creek. The highest pre-fire TSS concentrations were 334 and 7052 mg/L respectively, but these had been recorded at much higher discharges. The duration of the effects of the fire was variable, with the Yarrangobilly River returning to pre-fire TSS levels within 18 months; however, 4 years elapsed before TSS concentrations in Wallace's Creek returned to pre-fire levels.

Burgess *et al.* (1980; 1981) described sediment load responses to intense bushfires in several small catchments with dry sclerophyll forest in the Eden area of NSW. Although the immediate post-fire period was characterised by low rainfall, TSS concentrations showed marked increases and the magnitude of change observed was much greater than that associated with clear-fell logging and the effect lasted for a longer time.

Few studies have been carried out on the sediment production from small fuel reduction burning. Douglass & van Laer (1983) considered that small fires

associated with fuel reduction burning generally do not have any significant effect on water quality.

From the above fire studies, it is clear that major bushfires are capable of causing significant increases in suspended sediment load in Australian streams. However, the gross effects of bushfires on erosion and water quality tend to be of a short-term nature. Small bushfires and fuel reduction burning have negligible effects on stream TSS concentrations, due to their small areal extent and the rapid growth of post-burn vegetation, and the fact that the sites are often rehabilitated by forest managers after burning to minimise erosion.

3.2.4 Nutrients

Nutrient losses from forestry operations stem from surface erosion of sediments with adsorbed nutrients and from soil and fire ash leaching. Nutrient losses associated with timber harvest (biomass removal) are discussed separately in the EIS (Section 9).

In general, nutrient cycling is very efficient in forests (Carlyle 1986) and leaching losses are small (Cole & Rapp 1980). However, concentrations of inorganic nutrients in forest streams may increase during and following forestry operations, but usually by moderate amounts and for short periods depending on the extent and intensity of forestry operations (Chamberlin *et al.* 1991). The mobilisation of nutrients is tempered by their adsorption onto soil particles and by their uptake by micro-organisms that decompose stream detritus.

Nutrients that undergo transformations, such as nitrogen, appear to be the most sensitive to forest management activities, whereas nutrients that are normally strongly retained in forest soils (e.g. phosphorus) appear to be little affected and their inputs to streams do not appear to be altered by forest clearing (Golladay *et al.* 1992).

Forestry operations that increase either the rate or amount of water flow through a watershed are most likely to lower the nitrogen retention capacity of the watershed. In most cases, N losses through leaching to stream waters are relatively short-lived and low in magnitude compared to losses associated with biomass removal, fire and erosion losses. Mackay & Robinson (1987) reported substantial increases in nitrate-nitrogen (NO_3-N) concentration following bushfires. Increased NO_3-N concentrations in streams after a fire have been ascribed to enhanced nitrification and reduced demand for NO_3-N by vegetation (Tiedemann *et al.* 1978). Post-fire increases in ammoniacal nitrogen (NH_4-N) are generally small and very short-lived, due to nitrification.

Biological decomposition of slash and stumps releases potassium and dissolved organic carbon (DOC), while nitrate may decrease or increase depending on particular circumstances. Breakdown of organic matter leads to the soil water being supplied with additional DOC, organic nitrogen, and nitrate from the nitrification of ammonium. Dissolved organic matter is a major transport pathway for the loss of N

from forest ecosystems that are not experiencing severe erosion (Sollins & McCorison 1981).

Phosphorus (P) in forest soils is mostly present in organic forms or is temporary converted to organic forms in the early stages of litter decomposition by microbial activity (Harrison 1988). Since P has a low solubility it has a tendency to accumulate in the solid phase, and P transport and export from forests takes place chiefly in the particulate form. Therefore, harvesting activities that accelerate erosion and sediment mobilisation to the natural drainage also tend to increase P removal.

Nutrient losses associated with fires vary according the areal extent of the fire, intensity of the fire, and post-fire hydrological conditions. Once a fire has occurred, it is the runoff that is of immediate concern from the standpoint of water quality in forest streams. The lack of vegetation to hold the soil combined with an enhanced runoff from reduced transpiration and impedance of flow commonly leads to increased erosion and transport of sediments from burned areas in a catchment. These probably are the most dramatic and important deleterious water-quality responses associated with fire.

Increased concentrations of nutrients in streams draining catchments that have been exposed to moderate and large-scale fires generally result from:

a) direct precipitation of ash in streams (Spencer & Hauer 1991)

b) nutrient transport from ground waters and overland flow which have been in contact with ash (Grier & Cole 1971)

Few studies, however, have addressed the nutrient losses associated with small prescribed fires or fuel reduction burnings, and most studies have dealt with the effects of large-scale bushfires. The effects of burning operations on stream water quality have been reviewed by Wood (1975). In general, following regeneration burning, levels of nitrogen and phosphorus in streams can be as much as doubled, with a return to pre-harvesting levels generally coinciding with erosion rates, which decline over a number of years following harvesting. Langford & O'Shaughnessy (1980) studied logging and regeneration burning in the Melbourne Metropolitan Board of Works (MMBW) experimental catchments at Coranderrk and showed that no significant changes in N and P levels in streams followed experimental harvesting and burning.

Kauffman *et al.* (1992) considered that nitrogen losses fire-adapted, eucalyptus-dominated forests in which low quantities of biomass are consumed are much lower than in North American forests. As opposed to wild fires, Douglass & van Laer (1983) considered that small fires associated with fuel reduction burning generally do not have any significant effect on water quality or export of dissolved solids from forested catchments.

The concentrations of nutrients and other ions from forestry-disturbed watersheds are diminished to a significant extent by dilution as stream size increases and by biological uptake in the stream.

3.3 Interaction of Forest Management and Aquatic Biology

Very few studies of the effects of forestry operations on stream aquatic life have been carried out in Australia. Thus the full nature and extent of aquatic biological response to this form of disturbance has to be assessed from first principles, reference to international literature and professional judgement.

Interactions of forest management on aquatic biological habitats, macro-invertebrates, fish and water-associated fauna are reviewed below.

3.3.1 Aquatic Biological Habitats

Changes in stream stability following forestry management activities (harvesting, thinning, and road construction) can affect aquatic biological and streamline terrestrial habitats. Habitat changes imposed by forestry operations comprise physical changes to stream bed composition (sedimentation and woody debris) and to stream flow.

Besides in-stream aquatic biological habitats, river and stream corridors provide a variety of natural resources which includes riparian habitat for terrestrial and amphibious wildlife. These habitats may be susceptible to inundation and overbank sedimentation associated with flood flows.

The principal forestry-induced changes in sedimentation, large woody debris and particulate organic matter are reviewed below.

Sedimentation

Section 3.1 has shown that forestry operations increase sediment loads in the natural drainage. When the sediment carrying capacity of forest streams is exceeded, deposition of coarse material results and is often characterised by highly-localised but temporary sedimentation of stream beds.

Sedimentation changes the structural diversity of stream habitats, generally causing a loss of riffle habitat through filling and higher rates of sedimentation in pool habitats.

The effects of sedimentation on the stream habitats of macroinvertebrates, fish and water-associated fauna are reviewed in Sections 3.3.2, 3.3.3 and 3.3.4.

Large woody debris

All forest streams are characterised by the presence of large woody debris (LWD) comprised of tree roots, branches and twigs; coarse particulate organic matter (CPOM) comprised of leaves, bark and plant debris; and fine particulate organic matter (FPOM) comprised of leaf/plant fragments and detritus. The riparian forest is the major source of terrestrial organic matter input to the streams.

LWD controls many of the structural and functional properties of smaller streams in forested areas (Bilby & Ward 1991). LWD affects stream channel form through the

formation and stabilisation of pools, waterfalls, and gravel bars and has a key role in streams by determining the distribution of both CPOM and FPOM and macroinvertebrates that consume these organic particulates. Fish make use of LWD which increases the structural diversity of fish habitat and feed on the macroinvertebrate fauna associated with the LWD and deposits of CPOM and FPOM. LWD tends to decrease with increasing stream size, and old-growth forest sites tend to have more wood than similarly sized streams at second growth or harvested sites.

In upland forest streams woody debris jams retain organic matter trap sediments and create areas of slow-flowing water. In the low-gradient soft-bottom rivers downstream of forested catchments, submerged wood (or snags) are the preferred habitat for a number of fish species and aquatic macroinvertebrates. Submerged wood (snags) in streams is often a key structural habitat component for fish and aquatic macroinvertebrates in Australian streams (O'Connor 1992).

During forestry operations short-term increases in the supply of woody and organic material may result from materials transported in runoff, especially after high-rainfall and storm events. Subsequent rising and storm flows, however, evacuate any deposited materials and transport them downstream. Following forestry operations, sources of woody and organic material are reduced by tree removal, and streams generally may have reduced levels of woody debris and typically export more organic matter (due to less retention) than streams draining unlogged catchments.

Particulate organic matter (POM)

The communities of most streams and small rivers depend almost entirely on inputs of organic matter from the terrestrial environment (Cummins 1974), and the quality and quantity of these inputs largely determines the functional structure of the communities (Anderson & Sedell 1979). Disturbance of forests, therefore, is likely to affect the aquatic fauna of forested catchments through changes in the sources, cycling and fate of organic carbon.

Logging in forests can significantly change the amount of particulate organic matter (POM), mostly wood-derived particles, entering and remaining in streams and causing changes in stream habitat diversity and food supplies. A major proportion of the standing stock of POM in forest streams is comprised of large woody debris which can affect stream channels through the formation and stabilisation of pools, waterfalls, and gravel bars. Riffle and pool reaches of forest streams receiving added inputs of coarse POM (large woody debris, twigs etc) and fine POM (leaves, vegetation fragments) can lead to changes in the standing stocks and community structure of aquatic invertebrates and fish.

3.3.2 Macroinvertebrates

The effects of forestry management activities on stream macroinvertebrate populations result from the physical alteration of stream habitats (sediment deposition and woody debris alterations), changes in water quality (increased suspended sediment and nutrient concentrations and changes in temperature and dissolved regimes), and indirect impacts on macroinvertebrate food resources (changes in microbial populations, algae and detritus).

Very few studies have been carried out on the effects of forestry operations on stream macroinvertebrate communities in Australia. However, since the environmental effects of forestry operations on stream macroinvertebrate communities stem mainly from the effects of in-stream sedimentation and elevated suspended sediment concentrations, the resultant generic impacts on macroinvertebrates are reviewed.

Effects of in-stream sedimentation on macroinvertebrates

Upon deposition, suspended sediments may suffocate or bury macroinvertebrates and their food resources (e.g., benthic algae and detritus) and cause a loss of habitat through filling. Interstitial filling of the stony substratum of riffle habitats reduces their structural diversity by reducing void space and covering stone surfaces with fine silt which eliminates attachment and anchoring points for specific macroinvertebrates. A reduction in the numbers and kinds of riffle-associated macroinvertebrate species is normally evidenced, especially since more than 70% of stream macroinvertebrates live in the top 10 cm of the stream bed (Hynes 1972). In most instances of heavy in-stream sedimentation there is a change in macroinvertebrate community structure rather than a total loss of the fauna (Ryan 1991).

Where excessive sediments are present in a stream, a significant proportion of the total sediment moved may be present as bed load material, and the presence of a continually shifting substratum is not conducive to macroinvertebrate colonisation. This is evidenced in the depauperate macroinvertebrate community residing in the pool reaches of streams having a sandy substratum.

Effects of suspended sediments on macroinvertebrates

The generalised effects of suspended solids on macroinvertebrates may be considered both directly and indirectly at the organism, population and community level. These include lethal effects (mortality of adult, larval or nymphal life stages) and sub-lethal effects (suppression of growth and productivity).

The direct effects of excessive concentrations of suspended solids include abrasion to body integuments, particularly the gills causing tissue damage or clogging, and clogging of the filtering or trapping apparatus of stream macroinvertebrates.

Indirect effects of suspended sediments and attendant turbidity include reduction of stream primary productivity, and this may immediately reduce the energy available to enter the food chain. However, such effects are minimal in forest streams where most energy is derived from inputs of organic matter from the forests. Other indirect effects include displacement of macroinvertebrates by movement away from waters having continuously elevated TSS concentrations (e.g., atyiid prawns and larger more mobile macroinvertebrates) and by drift (Rosenberg & Wiens 1975).

3.3.3 Fish

The effects of forestry operations on fish populations result from the physical alteration of fish habitats, (sediment deposition and woody debris alterations), changes in water quality (increased suspended sediment concentrations, turbidity and nutrients and changes in dissolved oxygen regimes), and indirect impacts on fish food resources (changes in macroinvertebrate populations, algae and detritus).

Of much more concern, is the deterioration of water quality associated with low and average flows in streams to which fish are exposed to for most of the time. Stream waters from forested catchments tend to be very low in suspended solids and conducive to fish productivity. During and following forestry operations, the trend towards elevated suspended solids concentrations is less favourable to fish populations, ecologically.

As is the case with the effects of forestry operations on stream macroinvertebrate communities, little work has been done on Australian fish. Although it may be applicable to apply the results of overseas studies of salmonids (trout and salmon) to the Australian situation, it is perhaps not wise to do so with Australian native fish species. However, the generic effects of sedimentation, elevated suspended sediment concentrations and depressed dissolved oxygen regimes on fish are applicable because of the basic biology and ecological responses of freshwater fish *per se*.

The main effects of forestry operations stems from direct and indirect impacts associated with in-stream sedimentation and elevated concentrations of suspended sediments and to a lesser extent, the reduction of dissolved oxygen. These effects are reviewed below.

Effects of in-stream sedimentation on fish

In-stream sedimentation derived from forestry operations is known to cause changes in fish habitat. The responses of fish populations to these changes varies with the species, life stage, season, and habitat requirements.

Upon deposition, suspended sediments may suffocate or bury fish food organisms (macroinvertebrates, benthic algae and detritus) and cause a loss of habitat through filling. Interstitial filling of stony substrata reduces the structural diversity of riffle habitats by reducing void space and covering stone surfaces with fine silt. A reduction in the numbers and kinds of riffle-associated fish species may be evidenced. Where excessive sediments are present in a stream, a significant proportion of the total sediment may be present as bed load material, and the

presence of a continually shifting substratum is not conducive to macroinvertebrate colonisation. This represents an indirect effect on fish by reducing the quantity and quality of food resources.

In the case of those fish species that deposit eggs in the gravels (redds) of riffle reaches or attached to submerged objects, the eggs are vulnerable to sediment smothering, which reduces the supply of oxygenated water flow through the redds (Hayes *et al.* 1992). Silt deposition may cause widespread egg mortality and many salmonids will not spawn in gravels that have become silted (Alabaster & Lloyd 1982). Of the few Australian studies, Koehn & O'Connor (1990) suggested that in silted streams the freshwater blackfish (*Gadopsis marmoratus*) may not be able to find sediment-free sites for egg adhesion. Blyth & Jackson (1985) studying Victorian streams in East Gippsland also concluded that fish eggs and larvae were likely to be affected by sediment deposition.

For forestry operations, it is considered important to distinguish between permanent, long-term and short-term effects of in-stream sedimentation. Hamilton (1961) showed that severe and persistent in-stream sedimentation is required to induce population changes in stream fauna. In an overseas study, Winterbourn & Rounick (1985) showed that streams on the West Coast of South Island (New Zealand) suffered a severe short-term impact from logging activities, but that subsequent storms removed almost all of the deposits.

Recovery from the effects of in-stream sedimentation on fish habitats is usually rapid once the source of sediment supply is removed or rising or flood flows scour and resuspend deposited sediments and transport them downstream with little re-deposition.

Effects of suspended sediments on fish

Numerous studies have documented the effects of total suspended solids (TSS) and their deposition on fish populations (Alabaster & Lloyd 1982; Ryan 1991; Peters 1965; Bruton 1985; Hayes *et al.* 1992). Few studies, however, have been carried out to determine the effects of elevated TSS concentrations on fish in Australian streams, and most of these have addressed mining impacts.

The generalised effects of suspended solids on fish may be considered both directly and indirectly at the both species and population level. Lethal effects include mortality of fish and eggs and sub-lethal effects include suppression of growth and productivity, and behavioural avoidance.

Excessive concentrations of suspended solids tend to be abrasive to body integuments, particularly the gills, causing tissue damage or clogging of the gill filaments and lamellae. Reduced survival of the eggs, embryos, eleutheroembryos, larvae, and juvenile stages in the life cycle of many fish species is a consequence of increased TSS concentrations and sedimentation.

The suppression of fish growth and productivity is a sub-lethal response to increased TSS concentrations and is mediated by various integrated combinations of the following responses:

- reduced food intake, either by virtue of a decreased food supply or absence of feeding during elevated TSS concentrations. The latter may be brought about by loss of appetite or by reduced visibility (turbidity induced) for prey capture or foraging.
- increased physiological stress.
- increased metabolic energy used for respiration and food foraging.
- reduced fecundity, fertility, and egg hatchability.
- depression of sexual maturity.
- emigration from affected stream reaches to areas of improved water quality (tributaries) or restored water quality (downstream displacement).
- reduced recruitment, for example loss of recruitment stock from other areas, upstream migration or downstream displacement of juvenile stock.
- increased susceptibility to disease and parasitism.

The mobility of fish implies that they may leave or not enter stream reaches containing elevated TSS concentrations. Long-term effects of continuously high TSS concentrations potentially include the interruption of fish migrations and other seasonal movements, resulting in temporary or long-term reductions in the fish population status of affected stream reaches. Increased TSS concentrations may isolate clean water tributaries from upstream migration, or isolate fish populations of spawning or natal areas from feeding grounds.

Effects of depressed dissolved oxygen regimes on fish

Forestry operations can impact upon the dissolved oxygen status of streams by increasing the amount of biodegradable organic matter associated with deposited sediments or by accelerating the entry and deposition of vegetable matter (leaves, bark, woody debris).

Where sediments have a high organic content as in runoff from forests subject to harvesting operations, biological decomposition of the organic content can create an oxygen demand in sediment deposits in streams, and lower the DO concentrations in the sediment interstices and overlying water. During critical periods of low flow, when stream oxygen levels may already be low, this can cause significant depressions in stream DO levels leading to fish mortality. A few overseas studies have implicated reduced DO regimes and fish mortalities (Graynoth 1979).

In general, streams draining upland forested catchments are seldom likely to show significant depressions in DO regimes, since the stream waters are constantly re-aerated by turbulent entrainment of atmospheric oxygen and by photosynthesis (e.g., benthic algae). However, streams draining coastal and low-lying forested

catchments are more susceptible to depressed DO regimes, which occur naturally during protracted periods of little or no rainfall.

3.3.4 Water-associated Fauna

Only those water-associated fauna that have in-stream habitat requirements, or depend on streams or other water bodies (e.g., swamps) for part of their reproductive cycle or for food materials are likely to be affected by forestry operations.

The principal interaction of forestry operations on water-associated fauna stems from in-stream sedimentation of macroinvertebrate habitats (removal of food resource) or from deteriorations in water quality that affect the survival or growth of aquatic stages (e.g., frog tadpoles). Reductions in the diversity, population densities and biomass of stream benthic macroinvertebrates can have an effect on platypuses, which are heavily reliant on this food (Grant 1990).

No studies on the effects of water quality on tadpoles in Australian streams were found in the literature. However, from first principles, the gills of tadpoles are simple in structure and less likely to be susceptible to damage from continuously high concentrations of suspended sediments than would be the case for fish gills which have a fine structure and are more susceptible to clogging. Tadpoles feed on stream-bottom algae, diatoms and detritus; therefore, forestry operations have the potential to impact upon tadpoles indirectly, by depleting their food resources.

MKES (1992) reviewed the effects of forestry operations on reptiles and amphibians in the FCNSW's Glen Innes, Mount Royal and Wingham Management Areas and concluded that there was no clear evidence to suggest logging has an adverse effect other than local and temporary. Indeed all reptile or amphibian species with a vulnerable and rare classification recorded in forestry areas were also recorded in logged and unlogged forests.

4. Environmental Impacts and Safeguards

4.1 General

This section discusses the significant impacts of the forestry management proposals on existing aquatic environments of the CMA and MMA. Where environmental impacts are unavoidable, the impacts are analysed and evaluated with an aim to quantifying the impact, and assessing its significance at the site, local and regional scales. The prediction and evaluation of these environmental impacts are based mainly on a knowledge of the existing aquatic environments likely to be affected, the results of specific investigations and surveys that provide quantitative data to support impact prediction and evaluation, desk audits of the scientific literature and professional judgement.

For most impacts on the aquatic environment, predictions are difficult to quantify and where accurate predictive capability is lacking, a correspondingly greater emphasis has been placed on baseline and long-term monitoring, which have been recommended for inclusion in the FCNSW's regional monitoring program (Section 5).

The FCNSW has established various mitigative and ameliorative measures and adopted various environmental management safeguards which are outlined in Section 4.3.

4.2 Classification of Impacts and Effects

Operational definitions of the spatial and temporal scale of environmental impacts have been made so that statements of the degree of impact have a precise meaning.

4.2.1 Spatial Scales

Aquatic environmental effects are evaluated in a spatial context, from the area of forestry operations (State forests) to the broad regional context (major rivers). Impacts on the aquatic environment are evaluated at three arbitrary spatial scales:

site scale: streams in the immediate vicinity of a forestry operation in a State forest or downstream environment within 1 km distance of the State forest lower boundary.

local scale: extending downstream from 'site' scale waters, and generally including larger streams and tributaries of the main river systems (e.g., Wilson's, Oxley, and Timbarra Rivers)

regional scale: extending downstream from 'local' scale waters, and principally includes the mainstreams of the upper Clarence River and the Richmond, Tweed and Brunswick Rivers.

4.2.2 Classification of Effects

The magnitude and, or, duration of environmental effects on the aquatic environment are defined below as impact criteria for hydrology, water quality and aquatic habitats.

Hydrology (stream flow)

major: Deviation in flow durations greater than 50% above background (pre-disturbance) hydrological conditions or in comparison with hydrological conditions in a representative (unlogged) Reference Forested Catchment (RFC).

moderate: Deviation in flow durations not greater than 50% above background (pre-disturbance) hydrological conditions or in comparison with hydrological conditions in a representative RFC.

minor: Deviation in flow durations not greater than 25% above background (pre-disturbance) or in comparison with hydrological conditions in a representative RFC.

insignificant: Basically undisturbed stream flows which can be based on comparison with either pre-disturbance hydrological conditions and stream flows or hydrological conditions and stream flows in a representative RFC.

The duration of the above impact criteria are discussed in text.

Water Quality

Water quality criteria specified in the *Clean Waters Act 1970* are not applied to forestry operations (see Section 4.3).

Based on the generalised effects of forestry operations on water quality of receiving waters, primary impacts are expected on concentrations of suspended sediments (and attendant turbidity), dissolved oxygen and nutrients. Therefore, impact criteria focus on the magnitude of changes in the concentrations of these parameters at median flows. Generally, it is under median flow conditions, that aquatic life is exposed to contaminants for most of the time. However, in cases where low flow conditions are critical (for example, dissolved oxygen), the impact criteria apply at low flows. Where deviations from these generalised impact criteria arise, they are explained in the text.

major: Concentrations of #substances are greater than 100% above or below background levels at average flow.

moderate: Concentrations of substances are 50% to 100% above or below background levels at average flow.

minor: Concentrations of substances are less than 50% above or below background levels at average flow.

insignificant: Concentrations of substance are less than 10% above or below background levels at average flow.

A water quality deterioration may result from either an increase or decrease in the concentration of the specified substance. For example, substances for which a decrease in concentration represents a water quality deterioration include dissolved oxygen and pH, and substances for which an increase in concentration represents a water quality deterioration include suspended sediments, turbidity, nutrients and pH (both cases). Subsequent water quality impact assessments include explanatory text about the specific substances at issue to clarify the impact.

Aquatic Habitats

major: Habitat alteration causes a measurable change in stream community structure or function that will persist beyond the cessation of forestry operations.

moderate: Habitat alteration causes a measurable change in stream community structure or function that will persist for the duration of forestry operations.

minor: Habitat alteration causes a measurable change in stream community structure or function that will persist for one year or less at the site scale during forestry operations.

insignificant: Habitat alteration causes no measurable change in stream community structure or function during or after forestry operations.

For each of these levels, five arbitrary classes are defined by the time of recovery from disturbance:

Class 1: No recovery of disturbed stream habitat.

Class 2: Recovery of stream habitats within 2 years following disturbance.

Class 3: Recovery of stream habitats within 1 year following disturbance.

Class 4: Recovery of stream habitats within 6 months following disturbance.

Class 5 No disturbance of stream habitat requiring recovery.

4.3 Environmental Management Safeguards

The FCNSW recognises that logging and road construction can lead to changes in runoff and water yield, sediment production and changes in stream water quality. Consequently, the production of timber may need to be constrained in some parts of State forest catchments and certain modification to harvesting techniques may be employed. By using this strategy, the production of timber with minimal disturbance to the aquatic environment can be compatible. These constraints will generally be imposed through the Preferred Management Priority (P.M.P) system, Codes of Logging Practice and the adoption of Standard Erosion Mitigation Guidelines for Logging (SEMGL). Adherence to these environmental management prescriptions is part of the Licence agreement between the Environmental Protection Authority and the FCNSW and, provided these are fully implemented, the FCNSW forestry operations are exempt from the application of water quality criteria specified in the *Clean Waters Act 1970* (Derek Elms. EPA, pers. comm.)

The potential for erosion of sediments will be minimised by safeguards adopted by the FCNSW as outlined in the new SEMGL,which includes erosion protection measures, and through the supervision of forestry operations. In the planning stage, the objectives of the SEMGL are clearly defined and stated, and procedures to track the management plan have been identified by the FCNSW, thus ensuring that the stated objectives retain their visibility during the implementation phase.

Effective implementation of SEMGL by the FCNSW will serve to minimise sediment mobilisation and entry to drainage channels and streams. All forest management measures that minimise sediment erosion and transport to forest streams will benefit downstream water quality by reducing in-stream sedimentation, reducing turbidity (suspended sediment concentrations) and minimising losses of nutrients sorbed onto fine sediments.

A summary of the important FCNSW environmental management and stream protection measures are as follows.

- adoption and implementation of SEMGL.
- implementation of a Code of Logging Practice with regular supervision by FCNSW officers.
- planning of harvesting and thinning operations and fuel reduction burning to take account of potential environmental impacts.
- retention of vegetation filter strips along prescribed streams (Table 14) and specified streams:
    - Filter strips - FCNSW's Code of Logging Practice includes provision for strips of retained vegetation of 20 m width each side of streams with a catchment area equal to or exceeding 30 ha. The SEMGL are less stringent and state that strips of retained vegetation of 20 m width each side of streams with a catchment area equal to or exceeding 100 ha., or 40 ha. where the erosion hazard is high.
    - Protection strips - strips of retained vegetation of 10 m width each side of drainage features where no ground disturbance by machinery is permitted.

Table 14

Prescribed streams in the Casino and Murwillumbah Management Areas (After FCNSW, Ron Winwood-Smith, Regional Cartographer)

River/stream	River/stream	River/stream
Casino Management Area:		
Mongogarie Creek	Busby's Creek	Phillip Creek
Myrtle Creek	Four Mile Creek	Cherry Tree Creek
Shannon Brook	Barrett's Creek	Six Mile Creek
Batten's Bight Creek	Myall Creek	Camira Creek
Sportman's Creek	Banyabba Creek	Sandy Creek
Camp Creek	Bungawalbin Creek	Mangrove Creek
Broadwater Creek	Peacock Creek	Tunglebung Creek
Culmaran Creek	Dulgigin Creek	Ewingar Creek
Washpool Creek		
Murwillumbah Management Area:		
Brays Creek	Byrill Creek	Wollumbin Creek
Dunbible Creek	Christies Creek	Smiths Creek
Chowan Creek	Rolands Creek	Brunswick River
Wilson's River	Coopers Creek	Rocky Creek
Doon Doon Creek		

- adoption of the best erosion control processes, namely to close operations during wet weather conditions to prevent an increase in turbidity while overland flow is in progress, and timing mechanical operations to suit soil conditions.
- drainage interception and diversion of sedimented runoff away from stream channels onto undisturbed areas.
- other erosion control and water quality protection measures as described in the new SEMGL.

PMP classifications and extensions

Extensions of the PMP 1.1.7 (Flora and Fauna) Strips along water courses have been proposed for certain locations, from the current 40 m width each side, to 100 m width each side. Specific examples are along Batten's Bight, Barrett's and Six Mile Creek in the Moratorium Area of Mount Marsh State forest.

PMP Class 1.1.9 (Aboriginal) classification zones will be established in Billilimbra and Mt. Marsh State forests in the CMA.

PMP 1.1.6 (Visual) classification zones will be established in some State forests, for example, Mount Marsh State forest in the CMA.

4.4 Scale of Proposed Forestry Operations

The scale of proposed new road networks and harvesting operations are described below and used to assess aquatic environmental impacts.

4.4.1 Proposed Road Network

As at 30th June 1990, approximately 700 km of permanent roads of Class III standard or better and 717 km of Class IV road have been constructed and are currently maintained in the CMA (FCNSW, Ron Fussell, pers. comm.). The FCNSW construction of permanent access roading commenced in the 1940's and roads within the State forests have evolved over the ensuing years with gradual improvements in standards of planning, design and construction.

The FCNSW proposes to build new road networks in the Mt. Marsh, Billilimbra, Washpool, Ewingar and Bungabbee State forests of the CMA. No new road construction is proposed for State forests in the MMA during the next 10-year period. Table 15 gives details of new road networks planned in specified State forests of the CMA.

4.4.2 General Harvesting Operations

Combined harvesting and thinning operations for State forests in CMA and MMA over the next 10-year period are expected to average 5000 ha/yr. Table 16 gives details of State forests and proposed harvesting rates.

Harvesting operations may be for a variety of products including quota sawlogs, small sawlogs, poles, sleepers, salvage, and veneer. The intensity of operations and the resultant disturbances are related to the type of operation. For example a quota-driven harvesting operation may result in 30% ground disturbance and up to 80% canopy disturbance across a compartment. However, a thinning operation for posts or poles, say in a regrowth forest, may result in less than 5% ground disturbance and minimal canopy disturbance.

Considering the next 10-year period, an operation for any of the above materials, or an integrated operation in which a number of products are taken, may occur within all areas proposed in the CMA and MMA. Areas to be harvested may be separated into a) quota-driven operations in the moratorium areas of Washpool/Billilimbra and Mount Marsh State forests; b) quota-driven operations in regrowth forests; and c) integrated and miscellaneous operations in regrowth forests. Most of the remaining State forests within the CMA and MMA fall in the last category, which will be subject to selective harvesting for thinning purposes to improve stand growth. Very little road construction would be required with disturbance limited to snig tracks, a canopy disturbance of up to 40% across a compartment, and ground disturbance of less than 20%.

Table 15

Total lengths of proposed roads in selected State forests of the Casino Management Area for the period January 1994 to December 2003

State forest	Road Class	Proposed (km)
Washpool/Billilimbra:		
	secondary road	21
	feeder road	8
	harvesting road	47
Mt. Marsh:		
	secondary road	18
	feeder road	3
	harvesting road	82
Bungabbee:		
	secondary road	3
	feeder road	6
	harvesting road	9

In general, harvesting operations across the MMA will be conducted in a mosaic pattern. This represents a less intensive (in time) and extensive (in area) harvesting policy, and water quality effects are expected to be less pronounced in the MMA.

4.5 Impacts on Hydrology

Hydrological impacts of the proposed forestry operations are described below for water yield and stream flow response.

4.5.1 Impacts on Water Yield

In general, there is expected to be a general pattern of change in water yield and stormflow in disturbed areas following harvesting operations and during the regeneration phase. Compared with a mature unlogged forest, the pattern is likely to consist of an initial short-term increase in water yield followed by a long-term depletion in yield.

Current harvesting proposals need to be better detailed in relation to catchment areas and appropriate models developed, if estimates of the extent of any increases or reductions in water yield for specific catchments are to be estimated.

Table 16

Proposed harvesting operations in the Casino Management Area over the next 10-year period (1994-2003)

State forest	Total area (ha.)	Proposed logging area (ha.)	Area affected (%)	Logging rate (ha./yr)	Duration of operations (yr)
**Quota-driven harvesting operations in Moratorium Areas:*					
Mount Marsh	7552	3100	41.0	600	5
Washpool	8982	1000	11.2	200	5
Billilimbra	6614	3500	53.0	300	10
†Quota-driven harvesting operations in regrowth areas:					
Billilimbra	6614	1000	15.1	200	5
Gibberagee	12,493	300	2.4	300	1
Bungabbee	1470	1300	88.4	650	2
Mount Belmore	9686	6500	67.1	650	10
Royal Camp	2820	850	30.1	425	2
Double Duke	9686	200	2.0	200	1
Banyabba	5608	3206	57.2	1000	3

* % average crown removal rate estimated at 15%.

† % average crown removal rate estimated at 10%

Takes account of annual logging rate and duration of harvesting operations.

However, Table 17 presents first pass, conservative estimates of changes in annual water yield from disturbed areas of the State forests in the CMA based on a rate of 40 mm/yr per 10% reduction in crown cover (Bosch & Hewlett 1982). All harvesting proposed will be light to moderate selective logging, and per cent crown removal in logged areas is expected to vary from 10% in most cases up to 15% in parts of Washpool/Billilimbra/Mount Marsh State forests. To place the localised mean annual increases in water yield in perspective, and by way of example, annual water yield from the Malara Creek catchment of Billilimbra State forest has been estimated as 350 mm/yr and, from Table 17 the increase in the mean annual water yield is predicted to be approximately 18 mm/yr, which represents an insignificant increase from 350 mm/yr to 368 mm/yr. This is expected to be a temporary increase as indicated by studies elsewhere, for example data from the Karuah hydrology research catchments (Cornish 1991).

Water yields at the catchment level are therefore expected to be insignificant to minor at the site scale, with no impacts at the local and regional scales.

Table 17

Predicted changes in water yield from forestry operations in the Casino Management Area based on Bosch & Hewlett's (1982) rate of 40 mm/yr per 10% reduction in cover

State forest	Total area (ha.)	Proposed logging area (ha.)	Area affected %	†Total cover reduction %	Logging rate (ha./yr)	#Increase in mean annual water yield (mm/yr)
**Quota-driven harvesting operations in Moratorium Areas:*						
Mount Marsh	7552	3100	41.0	6.2	600	14.4
Washpool	8982	1000	11.2	1.7	200	3.9
Billilimbra	6614	3500	53.0	7.9	300	14.8
†Quota-driven harvesting operations in regrowth areas:						
Billilimbra	6614	1000	15.1	1.5	200	3.6
Gibberagee	12,493	300	2.4	0.24	300	1.0
Bungabbee	1470	1300	88.4	8.8	650	26.6
Mount Belmore	9686	6500	67.1	6.7	650	14.8
Royal Camp	2820	850	30.1	3.0	425	9.0
Double Duke	9686	200	2.0	0.2	200	1.2
Banyabba	5608	3206	57.2	5.7	1000	14.2

* % average crown removal rate estimated at 15%.

† % average crown removal rate estimated at 10%

\# Takes account of annual logging rate and duration of harvesting operations.

The significance of this form of impact will have to be related to site specific conditions such as catchment conditions, rainfall patterns and the extent and intensity of harvesting operations.

Changes in water yield arising from forestry operations need to be verified by monitoring and this type of research is already being conducted by the FCNSW, for example, the continuing hydrological research program at the Karuah research catchments (Cornish, pers. comm.).

Stream flow response

It is difficult to predict with precision the magnitude and duration of any changes in stream flow response, as these depend on climate, aspect, changes in forest stand structure with time, distribution and percentage of timber and vegetation removed in harvesting, any changes in the infiltration characteristics of the forest floor soils and changes in water yield.

Within disturbed sub-catchments at the site scale (forest streams and drainage lines) stream flow response may be more significant, but depends quite strongly on mean annual rainfall and the area of land disturbed (Bosch & Hewlett 1982). Immediately, that is up to 3 years after harvesting, there may be increases in peak flows and baseflows in sub-catchments at the site scale, the magnitude and duration of which will be influenced by numerous factors. However, at the lower limit of the site scale (1 km downstream of forestry operations), hydrological impacts from any increases in water yield at the catchment level are unlikely to have any significant impacts on stream flow. No significant impacts on stream flow at the local and regional scales are anticipated because of greatly increased dilution.

4.5.2 Estimates of Sediment Production

Sediments discharged to streams draining the State forests of the CMA and MMA are expected to be increased by forestry operations, especially in the upland State forests where slopes and rainfall are greater. Accelerated rates of surface erosion are expected to prevail during and after road construction, ground preparation of log yards, harvesting operations and, to a minor extent, from sites of fuel reduction burning.

The potential for surface erosion is directly related to the amount of exposed forest soils and amount of bare compacted soil exposed to rainfall and runoff. The Soil Survey carried out by Veness & Associates (Veness 1993) indicates that the soils of the CMA and MMA generally are stable and have a low to moderate erosion potential. However, this potential increases with slope gradient and the extent and intensity of harvesting operations. Hence road surfaces, landings, snig tracks, ditches, and disturbed harvested areas are expected to contribute significant quantities of fine sediments to stream channels, especially in the upland State forests. Not all hillslope sediments will reach the stream channels, but roads and ditches will form important pathways.

The FCNSW's proposed forest management practices, which include SEMGL, will strongly influence the production of sediments from road construction and harvesting operations. The degree of sediment production from individual State forests will vary with catchment geology, microclimate, vegetation, soil stability, and terrain (slope). Natural revegetation plays an important role in minimising the period of major erosion risk and in stabilising disturbed areas.

Sediment production from road construction

New road networks are proposed within the CMA only. It is difficult to quantify the amount of sediment production likely to arise from the State forests; however, first pass approximations of fine sediment production from road construction have been made using published unit sediment production rates (Fahey & Coker 1992; and O'Shaughnessy & Jaysuriya 1987). These rates were then applied to the lengths and areas of new roading to determine sediment production and entry to natural water courses. Consideration was also given to terrain types traversed, and soil physical characteristics such as vulnerability to erosion and particle sizing.

The following assumptions have been made in order to give conservative estimates of fine sediment production from road construction in the State forests outlined in Table 18:

- Fahey & Coker (1992) studied fine sediment generation from upland forest roads in New Zealand. Fine sediment production values averaged 2.3 kg/m^2/yr, reaching a maximum of 7 kg/m^2/yr from fresh side-cast fill were typical for forest roads in hilly terrain and an annual rainfall of 1000 mm. A low, but conservative value of 2 kg/m^2/yr has been adopted in the present study and takes account of the FCNSW adoption of Standard Erosion Mitigation Guidelines for Logging (SEMGL), road alignments following hill ridge lines, and the retention of buffer strips of natural vegetation along stream lines. The adopted value of 2 kg/m^2/yr is also in agreement with the same rate of sediment production (20,000 kg/ha/yr = 2 kg/m^2/yr) from road construction determined in Melbourne Metropolitan Board of Works' catchments (O'Shaughnessy & Jayasuria 1987).

- Averages of size gradings of soil samples (Veness 1993) representing various Soil Mapping Units were interpolated to determine the <125 particle size fraction expected to report as suspended loads in streams draining the State forests. The derived percentages of very fine sediments (<125 µm), comprised of clays (<3.9 µm), silts (³3.9<63 µm) and very fine sands (³63<125µm), are as follows:

Soil Mapping Unit A (Alluvials)	=	30%	
Soil Mapping Unit B (Basalts)		=	45%
Soil Mapping Unit C (Metasediments)		=	35%
Soil Mapping Unit D (Granitoids)		=	20%
Soil Mapping Unit E (Grafton Formation)		=	30%
Soil Mapping Unit F (Kangaroo Ck. Sandstones)	=	20%	
Soil Mapping Unit G (Walloon Coal Measures)	=	40%	
Soil Mapping Unit H (Marburg Sediments)		=	25%
Soil Mapping Unit I (Volcanics)	=	35%	

- It is assumed that the bulk of road- and harvesting-derived sediments will enter the natural drainage during high rainfall events, thus 90% is assumed to be mobilised at high flows (10% exceedence flow) and the remaining 10% at median (50% exceedence flows). No sediment is expected to report to the natural drainage during base flows (Å90% exceedence flows), when overland flow is minimal.

- Estimates of sediment production are conservative and assume that no natural or artificial revegetation of exposed surficial soils takes place. They also assume that erosion mitigation and water diversion measures routinely undertaken are completely ineffectual during high runoff events.

Sediment production estimates are given in Table 18 below for representative State forests (Washpool/Billilimbra, Mount Marsh and Bungabbee) for which proposed new roading types and lengths were available (FCNSW, Ron Fussell, pers. comm.).

Table 18 gives estimates of the total sediment generated and potentially entering surface drainage in the first few years during and following road construction.

Estimates of annual sediment production from road construction activities are 55 t/yr, 168 t/yr and 77 t/yr, respectively for Washpool/Billilimbra, Mount Marsh and Bungabbee State forests. Of these total annual tonnages, the coarser fractions (>125 μm) of fine sediments are 41.5 t/yr, 127 t/yr and 31 t/yr respectively, and the very fine fractions (<125 μm) are 13.5 t/yr, 41 t/yr and 25 t/yr, respectively. The <125 μm size fraction is assumed to report as suspended sediment in the natural drainage (see Section 4.6.1).

Case examples (CMA only)

Two representative State forests located in the Gibraltar Range and Richmond Range have been selected for further analyses. Attachment A gives details for the Malara Creek Section of Billilimbra State forest and Attachment B gives details for the Moratorium Area of Mount Marsh State forest.

Billilimbra State forest (Malara Creek Section):

Attachment A should be referred to for background information and assumptions made in the derivation of sediment estimates. Total annual sediment generation, during first 5 years of road construction in the Malara Creek Section of Billilimbra State forest is estimated at 102 t/yr, comprising 77 t/yr of coarse material (>125 μm) and 25 t/yr of very fine material (<125 μm). The 25-t/yr very fine sediment value is used in calculating suspended sediment loads in the natural drainage (see Section 4.6.1).

Mount Marsh State forest (Moratorium Area):

Attachment B should be referred to for background information and assumptions made in the derivation of sediment production estimates. Three stream have catchments within the Moratorium Area of Mount Marsh State forest; these are: Six Mile Creek, Batten's Bight Creek and Barrett's Creek. Annual total sediment generated from road construction across the three catchments within the Moratorium Area during the first 5-year period of forestry operations is estimated at 144 t/yr comprised of 106 t/yr of coarse fine material (>125 μm) and 38 t/yr of very fine material (<125 μm). The tonnages of the very fine sediment fractions generated in each catchment are used in Section 4.6.1 to calculate suspended sediment loads in the three streams.

Sediment production from harvesting operations

Sediment production from harvesting operations alone are difficult to make, since progressive harvesting is often preceded or accompanied by road construction.

Table 18

Estimates of annual sediment production from road construction in selected State forests of the Casino Management Area

Source	Length (km)	*Width (m)	Total area (Ha)	Annual rate (ha/yr)	Annual sediment generated: Total (t/yr)	>125µm (t/yr)	<125µm (t/yr)
Washpool/Billilimbra State forest (1994-2001):							
Secondary road	21	4.2	8.82	1.26	25	19	6
Feeder roads	8	4.2	3.36	0.48	10	7.5	2.5
†Harvesting roads	47	3.0	7.05	1.01	20	15	5
				Annual rate =	55	41.5	13.5
				Total (7 yrs) =	385 t	290 t	95 t
Mount Marsh State forest (1993-1995):							
Secondary road	18	4.2	7.56	3.02	60	45	15
Feeder roads	3	4.2	1.26	0.50	10	7.5	2.5
†Harvesting roads	82	3.0	12.3	4.92	98	74	24
				Annual rate =	168	127	41
				Total (2.5 yrs) =	420 t	318 t	103 t
Bungabbee (1994-1995):							
Secondary road	5	4.2	2.10	2.10	21	12	9
Feeder roads	7	4.2	2.94	2.94	29	16	13
#Harvesting roads	9	3.0	2.70	2.70	27	15	12
				Annual rate =	77 t	31 t	25 t

* Formation width.

† Assumes that 50% of harvesting roads are constructed during the period.

Assumes that harvesting roads are constructed at same time as major roads.

It is difficult to quantify the amount of sediment production likely to arise from the State forests; however, first pass approximations of fine sediment production from harvesting operations have been made using published rates of erosion from harvesting operations (Moffat 1991), especially in upland areas. The rates published by Moffat (1991) range from 214 to 1300 kg/ha apply in the UK and, in the absence of published Australian rates of erosion from harvesting sites, a conservative value of 500 kg/ha was selected for this study. This value is below the mid-range of values reported by Moffat (1991) and takes account of the erosion mitigation safeguards implicit in the application of SEMGL in the State forests of the CMA and MMA. The conservative 500 kg/ha value represents a first approximation for

estimating erosion rates from harvesting operations in the CMA and MMA, in the absence of pertinent Australian values. The 500 kg/ha rate was subsequently applied to the areas of proposed harvesting operations in selected State forests of the CMA and MMA to determine sediment production and entry to the natural drainage.

The FCNSW intends to harvest approximately 5000 ha/yr of timber in the CMA and MMA. Estimates of harvesting-derived sediment production in the Malara Creek Section of Billilimbra State forest and the Moratorium Area of Mount Marsh State forest are detailed in Attachments A and B, respectively. Table 19 summarises estimates of sediment production from harvesting operations for these two State forests.

Table 19

Estimates of annual sediment production from harvesting operations in the Malara Creek Section of Billilimbra State forest and Moratorium Area of Mount Marsh State forest in the Casino Management Area

Source	Harvesting rate (ha/yr)	Annual sediment production (t/yr) Total	>125µm	<125µm
Billilimbra State forest - Malara Creek Section:				
Malara Creek catchment	†280	140	105	35
Mount Marsh State forest - Moratorium Area:				
Six Mile Creek catchment	150	75	56	19
Batten's Bight Creek catchment	50	25	19	6
Barrett's Creek catchment	45	23	17	6
	Total =	123	92	31

(See Attachments A and B for detailed analyses)

Annual total sediment production from harvesting operations in the Malara Creek section of Billilimbra State forest is estimated at 140 t/yr during the 10-year period of operations, comprised of 105 t/yr of coarser sediment (>125 µm) and 35 t/yr of very fine sediments (<125 µm). Similarly, corresponding values for the Moratorium Area of Mount Marsh State forest are 123 t/yr (total), 92 t/yr (>125 µm) and 31 t/yr (<125 µm). The very fine fractions are assumed to represent potential suspended sediment loads which are used to calculate total suspended sediment concentrations in the catchment streams of the two State forests.

Fate and impacts of forestry-derived sediments

The generalised fate of the above road construction- and harvesting-derived sediments will be determined by overland flow characteristics following rainfall. Where sediment generation is greater than the sediment carrying capacity of the overland flow, excess sediment will be deposited.

It is expected that the bulk of the coarser fractions of sediments will be retained within the State forests as overland flow deposits these sediments on convex slopes below batters and in depressions and drainage lines in close proximity to the sites of erosion along the new road alignments and in harvesting-disturbed areas. Sediments that do report to forest streams are expected to enter in an episodic manner, being transported in surface runoff associated with moderate to high rainfall events, with the bulk of material transported during storm events. In the streams, the coarser size fractions (>125 μm) of the sediments are expected to form part of the bed load and be transported downstream. Where excessive sediment loading occurs, sediment deposits are expected to develop in the short term and be highly localised to areas where sedimented runoff enters the creeks.

In-stream sedimentation impacts are therefore expected in the short-term, only at the site scale and in those streams in close proximity to road construction sites and other disturbed areas and, especially at the points of entry of sedimented surface runoff.

Sediment-impacted stream reaches are expected to recover rapidly as sources of sediments in disturbed areas diminish by consolidation and stabilisation through revegetation, and as in-stream deposited sediments are scoured and transported downstream by elevated and flood flows. No long-term in-stream sedimentation impacts at the site scale are anticipated.

No in-stream sedimentation impacts are expected at the local or regional scales, due to the small tonnages generated and high dilution capacities of the larger tributaries and rivers of the CMA and MMA.

The above estimates of sediment generation and mobilisation are based on conservative assumptions and, with the implementation of adequate erosion control measures (e.g., SEMGL) and progressive natural revegetation of exposed surficial soils, the actual amount of sediment mobilised by rainfall-based erosion and scour and entering the natural drainage will diminish with time. Therefore, estimates of the quantities of sediments reporting to the natural drainage system may be considered as overestimates.

The fate of suspended sediment loads generated by road construction and harvesting operations is assessed in Section 4.6.1.

4.6 Impacts on Water Quality

Assessments of impacts on water quality are discussed below for the principal parameters expected to be affected by forestry operations, namely, suspended sediments, temperature, dissolved oxygen, and nutrients.

4.6.1 Total Suspended Sediments

The very fine fractions (<125 μm) of sediments mobilised by road construction and harvesting operations are expected to report to internal drainage basins of the State forests and remain as suspended load. Total suspended sediment (TSS) concentrations can be predicted on the basis of diluting the annual tonnages of very fine sediments (<125 μm size fraction) entering the natural drainage into flows estimated at reference gauging points located in streams downstream of the State forests.

Predicted TSS concentrations from combined road construction and harvesting operations in Billilimbra and Mount Marsh State forests are given below. Predictions of TSS concentration increments from road construction and harvesting operations separately are given in Attachments A (Billilimbra) and B (Mount Marsh).

Predicted forestry-derived TSS concentrations

Estimates of annual suspended sediment loads, based on the <125 μm size fraction, from combined road construction and harvesting operations are 50 t/yr and 69 t/yr for the Malara Creek Section of Billilimbra State forest and the Moratorium Area of Mount Marsh State forest, respectively (see Attachments A and B). Predicted TSS concentrations in these State forest streams are given below.

Billilimbra State forest (Malara Creek Section)

Attachment A gives estimates of suspended load from road construction in Malara Creek, which drains the Malara Creek Section of Billilimbra State forest.

During the first 5 years of combined road construction and harvesting operations, TSS concentrations in Malara Creek at a point downstream of the State forest boundary are predicted to increase by 1 mg/L (20%) from a background value of 5 mg/L to 6 mg/L at median flows (50% exceedence flow), and increase by 7 mg/L (35%) at high flows (10% exceedence flow) from a background TSS value of 20 mg/l to 27 mg/L (see Attachment A). At extremely high flows accompanying storm events (e.g., <5% exceedence flows), TSS concentrations may be expected to increase by up to 10-fold in the very short term. No increases in TSS concentrations are predicted at base or very low flows, when sedimented overland flow is absent.

These forestry-derived increases in the TSS concentrations in Malara Creek during average to high flows represent minor impacts on water quality at the site scale, according to the definitions given in Section 4.2.2; however, they are expected to be short term, declining in time as erosion sites consolidate and stabilise through natural vegetation, thus reducing the sources of sediments.

At the local scale (Timbarra River) and regional scale (upper Clarence River), no significant impacts on water quality (TSS) are anticipated given the high dilution capacities of these receiving waters.

Mount Marsh State forest (Moratorium Area)

Attachment B should be referred to for background information, assumptions made in calculations, and predicted TSS concentrations in the three streams draining the Moratorium Area. The principal catchment within the Moratorium Area forms the headwaters of Six Mile Creek, and predicted TSS concentrations in this creek are presented.

During the first 5 years of forestry operations, TSS concentrations in Six Mile Creek under median flows are expected increase by 7 mg/L (140%), from a background level of 5 mg/L to 12 mg/L. At high flows, when most fine sediments will be mobilised, TSS concentrations in Six Mile Creek are expected to increase by 30 mg/L (150%) from an estimated background value of 20 mg/L to 50 mg/L. No significant increases in TSS concentrations are expected at base or low flows, due to the absence of sedimented overland flows.

Under median flow regimes, TSS concentrations in Batten's Bight Creek and Barrett's Creek are predicted to increase by 80% and 140% respectively.

In conclusion, considering the three draining the Moratorium Area of Mount Marsh State forest, predicted increases in TSS concentrations under median flow conditions range from 80% in Batten's Bight Creek to 140% in Six Mile Creek and Barrett's Creek, which represents a general doubling of TSS concentrations over background levels, representing moderate to major impacts on water quality.

Summary

Impacts on water quality (TSS) are expected only at the site scale in forest streams and at median to high flows. Forestry-derived increases in the TSS concentrations are predicted to range from 20% in Malara Creek (Billilimbra State forest) to 140% in Six mile Creek and Barrett's Creek (both draining Mount Marsh State forest). The TSS increments represent minor to major impacts on water quality (TSS) at the site scale, being between 20% (minor effect) and greater than 100% (major effect) above background levels at average flows, according to the impact criteria described in Section 4.2. No significant impacts on water quality (TSS) are expected at the local and regional scales due to significant dilution. The above predicted elevations TSS regimes are expected to be very short term, declining in time as sediment sources diminish and as erosion sites consolidate and stabilise through natural vegetation.

The magnitude of increased levels of TSS at the site scale for the two State forests investigated are generally in agreement with other studies (Cornish 1990; Anderson & Potts 1987; Langford & O'Shaughnessy 1980).

4.6.2 Water Temperature

Timber harvesting operations in the CMA and MMA are not expected to result in significant increases in stream water temperature due primarily to the maintenance of shade along stream channels through the retention of filter strips of riparian vegetation. These filter strips are expected to maintain current levels of shade on the surface of streams draining catchments greater than 30 ha.

Reduction in tree crown cover by harvesting operations has the potential to cause minor rises in the water temperatures of small forest streams and drainage lines where filter strips may not be retained. However, the maintenance of shade along the principal forest streams coupled with dilution water (having normal temperature ranges) from other streams draining undisturbed forested areas of the same catchment will serve to minimise any elevations in water temperature of the main forest streams at the site scale.

No impacts on water temperature are expected at the local or regional scales. The monitoring of water temperature in selected streams is a recommended component for inclusion in the FCNSW's regional monitoring program (see Section 5).

4.6.3 Dissolved Oxygen

Timber harvesting operations in the upland State forests of the CMA and MMA are not expected to result in any significant decreases in the dissolved oxygen (DO) regimes of streams. Turbulent entrainment of oxygen in upland State forest streams is expected to maintain existing levels of DO concentrations under all flow conditions. Therefore, no significant impacts on the DO regimes of streams draining upland State forest streams are expected at the site scale, and none in the receiving rivers at the local or regional scales.

No significant impacts on DO regimes at average to high flows in the low-lying and coastal State forests are expected; however, the potential for exacerbating occasional low-flow DO concentrations during low-flow conditions and high summer temperatures is considered a possibility. Any changes in DO regimes at low flows are likely to be brought about by changes in the amount and quality of particulate organic matter (POM) and dissolved organic matter (DOM) entering forest streams in surface runoff.

Section 2.3.3 showed the presence of a low DO regimes (6.2 mg/L or 70% saturation) in Barrett's Creek (Mt. Marsh State forest) in the CMA. The reason for the low DO concentration observed was not apparent; however, the catchment upstream of the sampling station was only 64% forested and the remainder was mainly pasture land. In general, all other streams having a higher proportion of forested catchment also had higher DO regimes. It is possible that harvesting operations may increase the supply of POM and DOM to this forest stream in the short term, with the capacity of creating additional oxygen demands during critical periods of low flow and high summer water temperatures. The potential exists for exacerbation of the occasional low DO regimes during critical low-flow periods, with additional stresses on aquatic life (see Section 4.7).

It is difficult to make any quantitative predictions on the amount or quality of forestry-derived organic matter entering streams, let alone predictions of the magnitude or duration of depressed DO regimes; therefore, emphasis has been placed on monitoring low DO concentrations on an opportunistic basis, and this has been recommended as a monitoring component for inclusion in the FCNSW's regional monitoring program (see Section 5).

4.6.4 Nutrients

Erosion and leaching are expected to be the major pathways of nutrients entering streams draining State forests in the CMA and the MMA.

Much of the surface soil erosion and hence nutrient loss occurs when timber harvesting and fuel reduction burning removes or consumes the organic materials that protect the soil surface. Sediment transport processes from compacted or disturbed areas will be the primary mechanisms of nutrient removal, but accelerated mineralisation and subsequent leaching of nutrients might also be significant. These processes are difficult to quantify and the magnitude of any increase in nutrient export will vary widely between State forests, and depend on site factors, climatic conditions and the effectiveness of forest management prescriptions. Implementation of SEMGL and other forest management measures that retain soils and vegetation and minimise surface erosion will also serve to minimise the export of nutrients sorbed onto fine sediments from disturbed forest areas.

The impact of nutrient losses associated with runoff from harvesting operations and fuel reduction burning are assessed below.

Harvesting operations and fuel reduction burning

Nutrients are likely to be lost from disturbed sites within the the State forests by topsoil erosion, and some leaching may occur from sites of fuel reduction burning and areas where vegetation decomposition is active. In all cases, nutrient losses are likely to be small and short-lived. Revegetation is expected to diminish soil erosion, and plant root systems and soil infiltration are expected to intercept and immobilise most the nutrients being released from decomposing organic matter in the forest floor of disturbed areas.

Nutrient losses associated with sediments and leaching sites subject to harvesting operations are expected to be low by virtue of the FCNSW environmental management measures and the small area of catchment affected.

Few nutrient studies have been documented in Australia for disturbed forested catchments and, where these have been carried out (e.g., Langford & O'Shaughnessy 1980; Mackay & Robinson 1987), they tend to be highly site-specific. It is considered inappropriate to make quantitative comparisons or extrapolate these site-specific data to analogous forested catchments in the CMA or MMA. Nonetheless, general principles have been established on the impact of forestry operations on nutrient erosional and leaching losses to streams, and preliminary assessments on the fate of phosphorus and nitrogen are considered below.

Phosphorus

The magnitude of phosphorus losses will depend on forest management practices and surface runoff. Since phosphorus has a low solubility and has a tendency to accumulate in the solid phase, most phosphorus transport will take place chiefly in the particulate form. As most phosphorus is adsorbed on the fine fractions of sediments, phosphorus losses to streams will tend to be associated with forestry-derived suspended loads. Section 4.6.1 assessed that short-term increases in TSS concentrations in forest streams at the site scale are generally expected to increase by between 20% and 140% at median flows and by 35% to 150% at high flows. Therefore, particulate phosphorus concentrations associated with these forestry-derived suspended sediments may also be expected to report in a proportionate manner to the natural drainage. However, fine sediments mobilised from road construction activities tend to be more or less of raw mineralogical composition, low in organic matter, and low in adsorbed phosphorus content; therefore, phosphorus concentrations are likely to be overestimated by the previous assumption. Other factors operate to diminish the predicted increase of phosphorus concentrations in the streams, for example settling of solids, biological uptake and dilution by increased water yield (Hart *et al.* 1992).

Section 2.3.3 showed that background concentrations of soluble reactive phosphorus (SRP) in streams draining State forests in the CMA were all very low with SRP values ranging from <2.0 µg/L in six out of the ten streams sampled to 22 µg/L in Gorge Creek (Richmond Range State forest). Similarly, low SRP concentrations were also recorded for streams draining State forests in the MMA, where SRP concentrations ranged from <2 µg/L in three out of the six streams sampled to 19 µg/L in Cooper's Creek (Nullum State forest).

It is anticipated that only a small proportion of any increased in P loading of streams draining the CMA and MMA will be in soluble form; therefore impacts on water quality (SRP) are expected to be insignificant to minor at the site scale, with no impacts discernible at the local and regional scales.

Since it is difficult to give quantitative predictions of either particulate or soluble phosphorus levels in streams following harvesting, emphasis has therefore been placed on monitoring to verify the expected low phosphorus concentrations in receiving streams loading. Sampling of stream waters for soluble phosphorus content is a recommended monitoring component for inclusion in the FCNSW's regional monitoring program (see Section 5).

Nitrogen

Particulate nitrogen losses through erosion of soils and surface litter and transport to stream waters are expected to be relatively short-lived and low in magnitude. The process is likely to be reversed rapidly as regeneration is established after harvesting.

Soluble nitrogen compounds such as ammoniacal nitrogen (NH_4-N) and nitrate nitrogen (NO_3-N) from sites of active vegetation decomposition are expected to report in surface runoff and enter catchment streams. However, increases in nitrate-

nitrogen concentrations are not a consistent result from harvesting operations (Bayley *et al.* 1991); therefore, the magnitude of changes in stream nitrate-nitrogen levels needs to be monitored as recommended in Section 5. If elevated concentrations of nitrate-nitrogen do occur, they are expected to be significant in streams at the site scale. No significant increases in soluble nitrogen are expected at the local or regional scales, due to increased dilution and downstream biological uptake.

The environmental significance of small elevations in soluble nitrogen species will also be limited by the fact that primary production in forested streams is low compared to external inputs of terrestrial organic matter. Threshold levels of 0.5 mg/L for total nitrogen set by the Australian Environment Council (AEC 1986), above which nuisance algal or macrophytic growth could be expected, are not expected to be exceeded in streams at the site, local or regional scales.

Fuel reduction burning

Sites of fuel reduction burning in the State forests of the CMA and MMA are expected to be small in areal extent compared to catchment or sub-catchment area; therefore, nutrient losses are expected to be minimal with no significant impacts on water quality (nutrient concentrations) at the site scale or beyond.

As opposed to wild fires, Douglass & van Laer (1983) considered that small fires associated with fuel reduction burning generally do not have any significant effect on water quality or export of dissolved solids from forested catchments.

4.7 Impacts on Aquatic Biology

Environmental effects of forestry operations on aquatic biological habitats and communities of the CMA and MMA are assessed below.

4.7.1 Aquatic Biological Habitats

Road construction and harvesting operations in State forests of the CMA and MMA have to varying degrees affected stream habitats for a considerable period of time. In the past, removal of streamside timber during logging was normal, and led to the degradation of stream habitats, but the FCNSW no longer carries out this practice. Due to the current practice of retaining filter strips of vegetation along stream lines, no significant alterations in the amount of woody debris and coarse and fine particulate organic matter entering the streams are expected at the site scale, and none at the local or regional scales.

The geology, climate, vegetation, soils, topography, hydrology and other characteristics of the CMA and MMA interact to influence the suitability of stream habitats for aquatic life. Superimposed upon the foregoing influences, forestry operations that affect the supply of sediments to streams and change water quantity can alter stream habitats. Section 4.5.1 indicated that no significance changes in stream-flow response were expected at the site, local or regional scales; therefore, stream habitats are not expected to be affected by changed flow regimes.

The principal impact on aquatic habitats is likely to stem from increased coarse sediment loading of forest streams at the site scale.

Impact of in-stream sedimentation on aquatic habitats

Section 4.5.2 gave estimates of coarse sediment production from combined road construction and harvesting operations in the CMA and from harvesting operations only in the MMA, and indicated that short-term, highly localised in-stream sedimentation impacts were expected to occur at the site scale, with no impacts at the local or regional scales.

Sediment-impacted reaches of forest streams are expected to present a loss or reduction in the quality of bottom habitat available to macroinvertebrates, fish and water-associated fauna. The area of stream bottom habitat affected, however, is expected to be small compared to the remaining unaffected areas of bottom habitat (sedimentation-free) in streams draining the State forests. Therefore, in-stream sedimentation impacts on aquatic habitats are expected to be insignificant in catchment-level streams at the site scale. No impacts on aquatic habitats at the local or regional scales are expected due to the absence of significant sedimentation.

The environmental significance of highly-localised, in-stream sedimentation impacts on streams arises mainly from aquatic habitat loss or degradation with subsequent impacts on the resident aquatic fauna (Sections 4.7.2, 4.7.3, and 4.7.4).

4.7.2 Macroinvertebrates

Impacts on macroinvertebrates are likely to arise from stream-bottom habitat alteration by sedimentation and changes in water quality. In general, macroinvertebrate responses to these alterations are expected to show insignificant to minor changes in community structure, function and diversity at the site scale, with no significant impacts at the local and regional scales.

Macroinvertebrates communities in disturbed streams are expected to recover rapidly as the sources of sediments cease and as water quality improves with time.

Specific impacts on aquatic macroinvertebrates inhabiting streams of the CMA and MMA are assessed below.

Impact of in-stream sedimentation

Section 3.4.1 indicated that sedimentation impacts were likely in stream reaches at sites in close proximity to sources of sediments and where sedimented surface runoff enters the forest streams. Significant, short-term sedimentation of these areas is likely to result in some infilling of riffle stony substrata and smothering of macroinvertebrates; however, subsequent clearing of sediments by rising and flood flows will again expose the substratum for macroinvertebrate colonisation from surrounding sediment-free areas and from downstream drift from unaffected reaches upstream. Minor impacts on stream bed macroinvertebrate habitats of sediment-impacted sites is expected; however, no significant impacts are expected on the overall macroinvertebrate communities of forest streams at the site scale, and none at the local or regional scales.

Impact of elevated suspended sediment concentrations

Section 4.6.1 indicated that the main impact of combined road construction and harvesting operations on water quality was an increase in total suspended sediment (TSS) concentrations at the site scale under median flows (20 to 140% increase) and high flows (75% to 150% increase).

Since the effects of concentrations of TSS on aquatic macroinvertebrates are time-concentration dependent, TSS concentrations occurring at median flows are the concentrations to which the macroinvertebrates are exposed to for most of the time. The increased range of between 20 to 140% above background TSS concentrations at median flows still remains within the natural range of TSS concentrations that macroinvertebrates frequently experience. In the short-term, macroinvertebrate community response to these elevated TSS concentrations is likely to be characterised by a minor reduction in the species diversity and densities of macroinvertebrate populations in the reaches of streams impacted by elevated TSS concentrations. Therefore, insignificant to minor impacts on macroinvertebrate communities of streams draining the State forests at the site scale are expected from elevated TSS concentrations during average flow conditions. No significant impacts are expected at the local and regional scales, due increased dilution and attenuation of forestry-derived TSS concentrations.

Exposure to high TSS concentrations at high flows is short term and most macroinvertebrate species are tolerant of such conditions, which they normally experience at frequent intervals. For example at the 10% exceedence high flow, elevated TSS concentrations are expected to occur 10% of the time, that is on approximately 36.5 days per year. High flows occur intermittently throughout the year, thus macroinvertebrates may be only exposed to high TSS concentrations only for a few consecutive days distributed throughout the year or during the rainy season. Macroinvertebrates are known to tolerate short-term exposure to TSS concentrations which are several hundred fold above the predicted TSS increments in this study. Intervening periods of low TSS concentrations at low to median flows allow recovery periods (windows) of exposure to background or low TSS concentrations. No significant impacts on macroinvertebrate communities of

streams draining the State forests at the site scale or greater are expected from elevated TSS concentrations at high flows.

4.7.3 Impacts on Fish

Impacts on fish may arise from the physical alteration of stream-bottom habitats by sedimentation and from forestry-imposed changes in water quality.

The main impacts of forestry operations on fish populations and fish habitats stem from the direct and indirect impacts of in-stream sedimentation and elevated TSS concentrations.

Impacts of in-stream sedimentation

Section 3.4.1 indicate that in-stream sedimentation of forest streams was likely at stream-bed sites in close proximity to the sources of sediments and where sedimented surface runoff enters the streams. Sediment-impacted areas are expected to represent a loss or degradation of fish habitat in terms of reducing the amount of available food (benthic macroinvertebrate food resource) and reducing the total area of stream-bed gravels available for use as reproductive sites (eggs in gravels or redds). However, these sediment-impacted areas represent a short-term, minor loss of total fish habitat in forest streams when compared with the remaining unaffected stream reaches. Alternative food supplies are continuously available in non-affected stream reaches and tributaries, and from upstream sources of macroinvertebrate drift and terrestrial inputs. No significant sedimentation impacts on the overall fish populations of forest streams at the site scale are expected, and none at the local and regional scales.

Impacts of elevated suspended sediment concentrations and turbidity

As with macroinvertebrates, the effects of TSS concentrations on fish are time-concentration dependent. Therefore, TSS concentrations occurring at average or median flows are the concentrations to which the fish are exposed for most of the time. The generic impacts of the predicted forestry-imposed doubling of TSS concentrations at median and high flows in the short term are assessed below.

Section 4.6.1 indicated that forestry-derived increases in TSS concentrations of between 20% to 140% above background levels (estimated at 5 mg/L) under median flows were expected. The 20% increment represents a TSS concentration of 6 mg/L compared to a background level of 5 mg/L, and a 140% increment represents a TSS concentration of 12 mg/L compared to the background value. These elevated TSS concentrations still remain within the natural range of TSS concentrations normally experienced by fish, and no significant impacts are expected on mainstream fish populations of forest streams at the site scale, and none at the local or regional scales. The potential exists for impacts on sediment-intolerant fish species, and this may be reflected by reductions in their population densities as fish are displaced upstream or downstream temporarily. However, this possibility requires monitoring (Section 5) so that the sensitivities of different fish species may be assessed.

Alabaster & Lloyd (1982) have demonstrated for a wide variety of freshwater fish from around the world that at TSS concentrations of less than 25 mg/L, no significant impact on fish populations is observed. It is assumed that Australian fish species and populations inhabiting streams of the CMA and MMA would present a similar biological response in terms of sediment tolerance, but this needs to be verified through monitoring (Section 5).

Exposure to high TSS concentrations at high flows is short term and most freshwater fish species are tolerant of such conditions, which they normally experience at frequent intervals. High flows occur for a small part of the time, for example, high flows (represented by the 10% exceedence flow) occur 10% of the time, that is on approximately 36.5 days per year, which will not be continuous. High flows occur intermittently throughout the year, thus fish may be only exposed to high TSS concentrations only for a few consecutive days distributed throughout the year or during the rainy season. Fish species such as salmonids are known to tolerate short-term exposure to TSS concentrations which are several hundred- or thousand-fold above the levels predicted for forest streams in both the CMA and MMA. Intervening periods of low TSS concentrations at low and median flows allow recovery periods (windows) of exposure to background low TSS concentrations. No significant impacts on mainstream fish populations are therefore expected from elevated concentrations of TSS at high flows at the site scale, and none at the local or regional scales.

As no significant increases in TSS concentrations are predicted at base or low flows; no impacts on fish populations are expected at the site, local or regional scales under low flow regimes.

4.7.4 Impacts on Water-Associated Fauna

No significant impacts on water-associated fauna (mammals, reptiles, amphibians) are expected given the minor sedimentation and water quality impacts outlined in preceding sections. Only those species which have significant in-stream habitat requirements (e.g., life cycle stages or aquatic food dependence) are likely to be susceptible to deterioration in the aquatic environments of streams draining the State forests of the CMA and MMA.

Platypuses

Section 4.7.3 indicated that no significant impacts were expected on the overall macroinvertebrate communities of forest streams at the site scale, and none at the local or regional scales. Therefore, as platypus food resources are expected to remain largely unaffected, no significant impacts on platypus food resources are expected at the site scale. However, within forest streams at the sub-catchment level, highly-localised, minor impacts on the macroinvertebrate habitats and populations of sediment-impacted reaches of forest streams were expected at the site scale (Section 4.7.3); therefore, the macroinvertebrate food resources of platypuses in these sediment-impacted stream reaches may be reduced. However, due to the small areal extent of habitat affected and, given alternative feeding areas and the large area of remaining stream reaches unaffected by sediments, overall stream platypus populations are not expected to be significantly impacted at the site scale,

with no impacts at the local or regional scales. Platypus populations in selected streams draining State forests should be monitored to confirm that the impacts are as predicted. This is a monitoring component for inclusion in the FCNSW's regional monitoring program (Section 5).

Amphibians

Frog tadpole populations may be impacted in those stream reaches affected by in-stream sedimentation, especially where a covering of fine sediments settles on stream-bed surfaces and obliterates tadpole food sources, such as algae and detritus (see Section 4.7.5). It is anticipated that tadpole populations in small forest streams at the sub-catchment level may be affected by forestry-imposed sediments, showing reductions in numbers brought about by mortality and downstream displacement. However, unaffected stream reaches and tributaries are expected to harbour and maintain tadpole populations, therefore no adverse effects on overall frog populations of streams and streamlines are expected at the catchment level at the site scale, and none at the local or regional scales. A validation monitoring component is recommended for inclusion in the FCNSW's regional monitoring program (Section 5).

4.7.5 Impacts on In-stream Primary Production

Impacts on primary production in streams and rivers of the CMA and MMA are likely to arise from in-stream sedimentation, increased turbidities and elevated nutrient concentrations.

Impacts of in-stream sedimentation

Communities of benthic algae, diatoms and macrophytes residing in sediment-impacted stream reaches are expected to respond structurally by a reduction in species diversity and density, with concomitant reductions in primary production. Section 4.5.2 indicated that relatively small areas of forest stream beds were likely to be impacted by settled sediments; therefore, impacts on overall stream primary productivity is expected to be insignificant at the site scale. No impacts at the local or regional scales are anticipated due to the absence of significant in-stream sedimentation.

Impact of suspended sediments and turbidity

Section 4.6.1 indicated that elevated total suspended sediment (TSS) concentrations were expected in the short-term at the site scale in forest streams. The environmental significance of increased TSS concentrations and the turbidities associated with these TSS levels is likely to be limited by the fact that primary production in forest streams is low compared to external inputs of terrestrial organic matter. Even so, increased TSS levels and elevated turbidities may affect primary production by either reducing the standing crop (biomass) of benthic algae, diatoms and macrophytes through the settling of fine sediments or depressing the rates of photosynthesis through reduced light levels. However, the shallowness of forest streams at the site scale is likely to minimise the impact of turbidity on primary production as photosynthetically-active light is expected penetrate the water column.

Turbidity impacts on primary production are expected at the site scale only and are expected to be short-term, with primary production resuming pre-disturbance levels as water quality improves through the recovery of water clarity as sediment sources diminish.

Impacts on primary production are therefore expected to be insignificant to minor at the site scale. No impacts on primary production are expected at the local and regional scales, due to reductions in turbidity by dilution downstream of site scale streams.

Impacts of nutrients on stream primary production

Section 4.6.4 indicated that insignificant to minor increases in the concentrations of soluble nutrients may be expected at the site scale, with no significant increases at the local or regional scales.

At the site scale, the stream ecosystems in the State forests are unlikely to be sensitive to the expected small increases in phosphorus loading in surface runoff from harvested areas, due to the phosphorus being present mainly in particulate form. Since it is the dissolved fraction of phosphorus which is most readily available for uptake by stream flora and fauna, no adverse stimulative impacts from elevated total phosphorus concentrations are expected at the site scale, and none at the local or regional scales. Similarly, short-term increases in the concentrations of nitrogen are expected at the site scale only, with none at the local and regional scales due to dilution.

The environmental significance of small elevations in soluble nutrients will also be limited by the fact that primary production in forested streams is low compared to external inputs of terrestrial organic matter. Threshold levels of 0.05 mg/L for total phosphorus and 0.5 mg/L for total nitrogen as set by the Australian Environment Council (AEC 1986) are not expected to be exceeded at the site scale from forestry operations, above which nuisance algal or macrophytic growth could be expected. Any potential stimulation of primary production is likely to be countered simultaneously by elevated turbidity levels. Confirmation of the expected insignificant to minor effects on stream primary production is required by validation monitoring, and water quality analysis is a monitoring component recommended for inclusion in the FCNSW's regional monitoring program (Section 5).

4.8 Impacts on Water Supplies

Impacts on water supplies in the CMA and MMA are assessed separately below.

4.8.1 Impacts on Water Supplies in the CMA

There are no major dams for water supplies having catchments within the CMA, and there are no significant irrigation, agricultural or other uses of water flowing from the area; therefore, there is no requirement for impact analyses.

4.8.2 Impacts on Water Supplies in the MMA

There are four existing water supply systems which depend to various degrees on contributions from catchments within the MMA (see Table 13, Section 2.5.5). The City of Lismore and the towns of Byron Bay, Brunswick Heads, and Evans Head and surrounding districts draw their water from the Rocky Creek Dam.

The catchment of the Rocky Creek Dam is of particular significance because it falls almost entirely (95%) within MMA. The value of protecting the Rocky Creek Dam catchment has been given formal recognition by P.M.P. 1.1.5 Special Emphasis Catchment Protection and by and self-imposed constraints (SEMGL or stricter codes) applied by the FCNSW on its forestry operations (see Section 2.5.5). The catchment is already subject to constraints on forestry activities, e.g., no harvesting in the 40-m vegetation strip around the foreshore, and these remain in force. The 40-m zone may be extended to 100 m under the new SEMGL. No problems associated with soils or suspended sediments have been noted for previous forestry operations in the catchment of Rocky Creek Dam, and this is expected to continue under the current harvesting plans. Any harvesting-imposed sediments entering Rocky Creek Dam are likely to settle out prior to offtake.

Since no new roads are proposed in the next 10-year period for the State forests of the MMA, there will be no sediment sources from road construction, although minor sediment loading is expected from existing road use and from snig tracks during harvesting operations. Harvesting operations are expected to be conducted in a mosaic pattern across the State forests of the MMA; therefore, selective harvesting operations within individual State forests are expected to be light with concomitantly low sediment production rates at the catchment level. No significant impacts on the water quality of water supply bodies (reservoirs and dams) are anticipated.

No problems associated with soils or suspended sediments have been noted for previous forestry operations in the catchment of Rocky Creek Dam. Cornish (1980) conducted a water quality study of Rocky Creek catchment to determine the effects of past and present logging operations on the water quality of Rocky Creek Dam in comparison with a parallel catchment (Little Rocky Creek) that had been logged in the past. His conclusions were that the effects of logging operations increased stream turbidity during wet weather, but that water entering the dam was of good quality on a significant proportion of the sampling dates and that the water of Rocky Creek Dam did not appear to have been significantly degraded. The settling of solids in Rocky Creek Dam improved water quality prior to offtake.

Since no significant elevations in suspended sediments are expected in local and regional scale rivers, no significant impacts are expected on water supplies which are abstracted from the Oxley and Tweed Rivers.

Validation monitoring of potential impacts on the water qualities of water supply bodies is a recommended component for inclusion in the FCNSW's Regional Monitoring Program (Section 5).

5. Environmental Monitoring Program

5.1 General

Environmental investigations carried out in support of this EIS have necessarily been based on a synoptic or "snapshot" picture of existing aquatic environmental conditions. The adequacy of the available data in relation to potential impacts has been assessed in this EIS; however, a more comprehensive baseline and on-going monitoring program needs to be undertaken as part of the FCNSW's regional monitoring program. A program will be developed by the FCNSW after the current round of EISs have been determined.

Monitoring principles, priorities, strategies, and recommended post-EIS environmental monitoring components for inclusion in the FCNSW's regional monitoring program are outlined below.

5.2 Monitoring Principles

The utility of using contiguous, or paired, watersheds to monitor and delineate forest management activity effects on streams is not absolute. Several years of data collection are necessary to establish a "reference point" for individual streams.

Since many of the State forests in the Casino District have been logged for over 70 years, State forest catchment streams should not be considered as pristine. The use of "near pristine" watersheds could provide an index or reference of potential natural condition. However, very few such areas are located in proximity to the CMA or MMA. Nearby National Parks may be considered to represent pristine conditions by some people, but many have been subject occasional hot wildfires over the last decade and are therefore not representative of forested watersheds of natural condition.

The search for and use of reference "pristine" forested watersheds is considered unnecessary. In order to evaluate the effects of the proposed forest management operations in the CMA and MMA, monitoring of selected streams before, during and after forestry operations is more applicable and pertinent to verifying predicted impacts. The results of the aquatic environment monitoring program can then be used to assess any adverse or unforeseen effects and, complemented by site inspections by the FCNSW forestry supervisor, remedial action may be undertaken to reduce or mitigate any adverse impacts.

5.3 Monitoring Priorities

The objective of aquatic environmental monitoring is the collection of baseline data against which future changes can be compared and assessed, and significant deviations from normal cyclical fluctuations be detected.

Most of the environmental effects of forest management activities on the aquatic environments of the CMA and MMA, for which the FCNSW holds management and monitoring responsibility, will result from accelerated rates of sediment entry to streams and changes in water quality both of which may induce aquatic biological responses at the organism, population and community levels.

This EIS has identified potential stream habitat and water quality changes at the site scale in both the upland, low-lying and coastal State forests. Efficient monitoring can only be achieved by direct monitoring of the important abiotic loading factors, which includes water quality parameters, and monitoring of key components of the aquatic biological communities (macroinvertebrates and fish) and water-associated fauna (e.g., platypuses, and frogs having an aquatic tadpole stage).

5.4 Monitoring Strategy

It is not recommended that aquatic environmental monitoring be conducted in all the State forests, as this would dilute sampling effort and be wasteful of the limited resources available. It is recommended that key monitoring stations be established on the principal streams draining selected regional State forests where significant impacts are predicted. Monitoring stations could be selected on the basis of the extent (in area) and intensity (in time) of proposed forestry operations, and should include a State forest subject to combined road construction and harvesting operations, and a State forest subject to harvesting operations only.

5.5 Monitoring Objectives

The objectives of the overall monitoring program are:

- to provide baseline data for the range of relevant natural environmental variables in those areas affected by road construction and harvesting operations.
- to evaluate the accuracy of general impact predictions made in this EIS (Section 4)
- to identify unforeseen effects and correct them by remedial action.
- to monitor operations for compliance with any permit conditions, including water quality criteria.
- to provide long-term monitoring data to show recovery of post-disturbance conditions.

5.6 Timing

The structure of the proposed monitoring program has been sequentially phased as follows:

- baseline - pre-disturbance baseline range of pertinent variables describing background conditions.
- validation monitoring - short term (fixed duration) intensive monitoring to verify predicted effects, leading to the design of the low intensity, long term, post-disturbance monitoring program.
- long-term monitoring - to be designed on the basis of the validation monitoring program results.

5.7 Scope

The proposed monitoring effort receives its focus from the predicted aquatic environmental effects outlined in this EIS, and addresses physical and chemical effects and their induced aquatic biological responses.

The scope of the monitoring program will be specifically restricted to predictable effects where direct pathways can be defined. This EIS has shown that most impacts on the aquatic environment are either insignificant or minor and occur at the site scale. Therefore emphasis has been placed on monitoring at the site scale (that is, forest stream environments). No monitoring of rivers at the local or regional scales are proposed; however, data for these rivers will be derived from Department of Water Resources water quality monitoring programs.

5.8 Proposed Monitoring Program Components

Components for baseline and validation monitoring during both road construction and harvesting operations in the CMA, and harvesting operations in the MMA are outlined below.

Monitoring Variables

Representative streams in the CMA and MMA could be monitored for the variables at the frequencies outlined in Table 20 (baseline program) and Table 21 (validation monitoring program).

The longer-term post-disturbance monitoring program will be derived from the results of the validation monitoring program, and the scope and contents of the program negotiated between the FCNSW and the NSW Environment Protection Authority.

6. Summary of Impacts

Impacts of the proposal on the aquatic environments of the CMA and MMA are summarised in Tables 22 and 23 respectively at the site, local and regional scales. The impacts on the aquatic environment are sufficiently localised, short-term and insignificant in most cases. The most significant impacts stem from forestry-imposed deteriorations in water quality brought about by elevated concentrations of suspended solids in forest streams during and immediately following road-construction and harvesting operations.

Table 20

Possible aquatic environment components for a baseline monitoring program

Component	Description	Frequency	Purpose
1. Water Quality	In situ sampling for water temperature, pH, dissolved oxygen, turbidity and specific conductance.	Fortnightly	Establish pre-disturbance, background range of water quality variables.
	Same analyses as above, except during specific flood flows and during extreme low flows.	Opportunistically	Establish pre-disturbance, background range of water quality variables during floods and extreme low flows
2. Hydrology	Monitor regional hydrology using data from gauging stations established by the Department of Water Resources..	At time of water sampling	Establish background range of flows at selected gauging stations in GMA.
3. Macroinvertebrates	Sample stream bed macroinvertebrate habitats using 6 replicate sampling units (core or box samplers).	Once-off	Establish background macroinvertebrate community structure, including species composition, diversity and population densities.
4. Fish	Sample fish populations residing in selected stream sampling sites.	Once-off	Establish background fish population structure, including species composition, diversity and relative abundance.
5. Water-associated fauna	Component of terrestrial fauna surveys.	Once-off	Determine water-associated species present or likely to be present in riparian habitats of selected streams.

Table 21

Possible aquatic environment components for a validation monitoring program

Component	Description	Frequency	Purpose
1. Water Quality	In situ sampling for water temperature, pH, dissolved oxygen, turbidity and specific conductance.	Monthly for first six months.	Determine post-disturbance range of water quality variables and compare with predicted EIS impacts and baseline water quality.
	Same analyses as above, except during specific flood flows and during extreme low flows.	Opportunistically	Determine post-disturbance range of water quality variables during floods and extreme low flows, and compare with predicted EIS impacts and baseline water quality.
2. Hydrology	Monitor regional hydrology using data from gauging stations established by the Department of Water Resources.	At time of water sampling	Continue monitoring long-term regional hydrology.
3. Macroinvertebrates	Sample stream bed macroinvertebrate habitats using 6 replicate sampling units (core or box samplers).	After first six months of harvesting operations.	Determine impacts on macroinvertebrate community structure, (species composition, diversity and population densities) and compare with baseline.
4. Fish	Sample fish populations residing in selected stream sampling sites.	After first six months of harvesting operations.	Determine impacts on macroinvertebrate community structure, (species composition, diversity and population densities) and compare with baseline.
5. Water-associated fauna	Component of terrestrial fauna surveys.	After first six months of harvesting operations.	Determine impacts on water-associated fauna and habitats and compare with baseline.

Table 22

Summary of impacts of the proposal on the aquatic environments of the Casino Management Area

Component	Range of impacts on the aquatic environment at the catchment level		
	Site Scale	Local Scale	Regional Scale
HYDROLOGY:			
In-stream sedimentation	minor	ns	ns
Water yield	ns	ns	ns
Stream flow	ns	ns	ns
		ns	ns
WATER QUALITY:			
Water temperature	ns	ns	ns
Total suspended sediments	minor/major	ns	ns
Dissolved oxygen	ns	ns	ns
Nutrients	ns/minor	ns	ns
MACROINVERTEBRATES:			
Habitat loss or degradation	ns	ns	ns
Suspended solids	ns/minor	ns	ns
FISH:			
Habitat loss or degradation	ns	ns	ns
Suspended solids	ns	ns	ns
PRIMARY PRODUCTION:			
Suspended solids (turbidity)	ns/minor	ns	ns
WATER-ASSOCIATED FAUNA:			
Habitat loss or degradation	ns	ns	ns
Suspended solids	ns	ns	ns
WATER RESOURCE USE:			
Water supplies	ns	ns	ns

Key: Impact scales(insignificant (ns), minor, moderate and major)

Table 23

Summary of impacts of the proposal on the aquatic environments of the Murwillumbah Management Area

Component	Range of impacts on the aquatic environment at the catchment level		
	Site Scale	Local Scale	Regional Scale
HYDROLOGY:			
In-stream sedimentation	minor	ns	ns
Water yield	ns	ns	ns
Stream flow	ns	ns	ns
		ns	ns
WATER QUALITY:			
Water temperature	ns	ns	ns
Total suspended sediments	minor/moder	ns	ns
Dissolved oxygen	ate	ns	ns
Nutrients	ns	ns	ns
	ns/minor		
MACROINVERTEBRATES:			
Habitat loss or degradation		ns	ns
Suspended solids	ns	ns	ns
	ns/minor		
FISH:			
Habitat loss or degradation		ns	ns
Suspended solids	ns	ns	ns
	ns		
PRIMARY PRODUCTION:			
Suspended solids (turbidity)		ns	ns
	ns/minor		
WATER-ASSOCIATED FAUNA:			
Habitat loss or degradation		ns	ns
Suspended solids	ns	ns	ns
	ns		
WATER RESOURCE USE:			
Water supplies		ns	ns
	ns		

Key: Impact scales(insignificant (ns), minor, moderate and major)

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Attachment A

Sediment production estimates for the Malara Creek section of Billilimbra State forest in the Casino Management Area

A1 General

A detailed roading plan was available for the Malara Creek Section of Billilimbra State forest. Figure A1 shows Billilimbra State forest, local drainage and the location of the proposed new roading. Detailed harvesting plans for compartments of Billilimbra State forest were not available for a comprehensive impact analysis; however, the rate of harvesting during the 10-year period 1994-2004 has been estimated at 280 ha/yr (FCNSW, Ron Fussell, pers. comm.).

Topography and Drainage

The terrain in the catchment is mostly steep and hilly, and rises to very steep terrain along the Desert Creek Fire Trail located on the ridge line of the Gibraltar Range to the south of Malara Creek catchment.

The total area of Billilimbra State forest was determined at 43,125 ha as estimated by planimetry of a 1:100,000 topographic survey map. Figure A1 shows the catchment of Malara Creek upstream of a reference gauging point (grid reference MN 375713) established for the prediction of suspended sediment concentrations. The total area of Malara Creek catchment upstream of the gauging point (see Figure A1) station is 7425 ha. of which approximately 80% of the catchment is covered by State forest and the remainder by non-state forest.

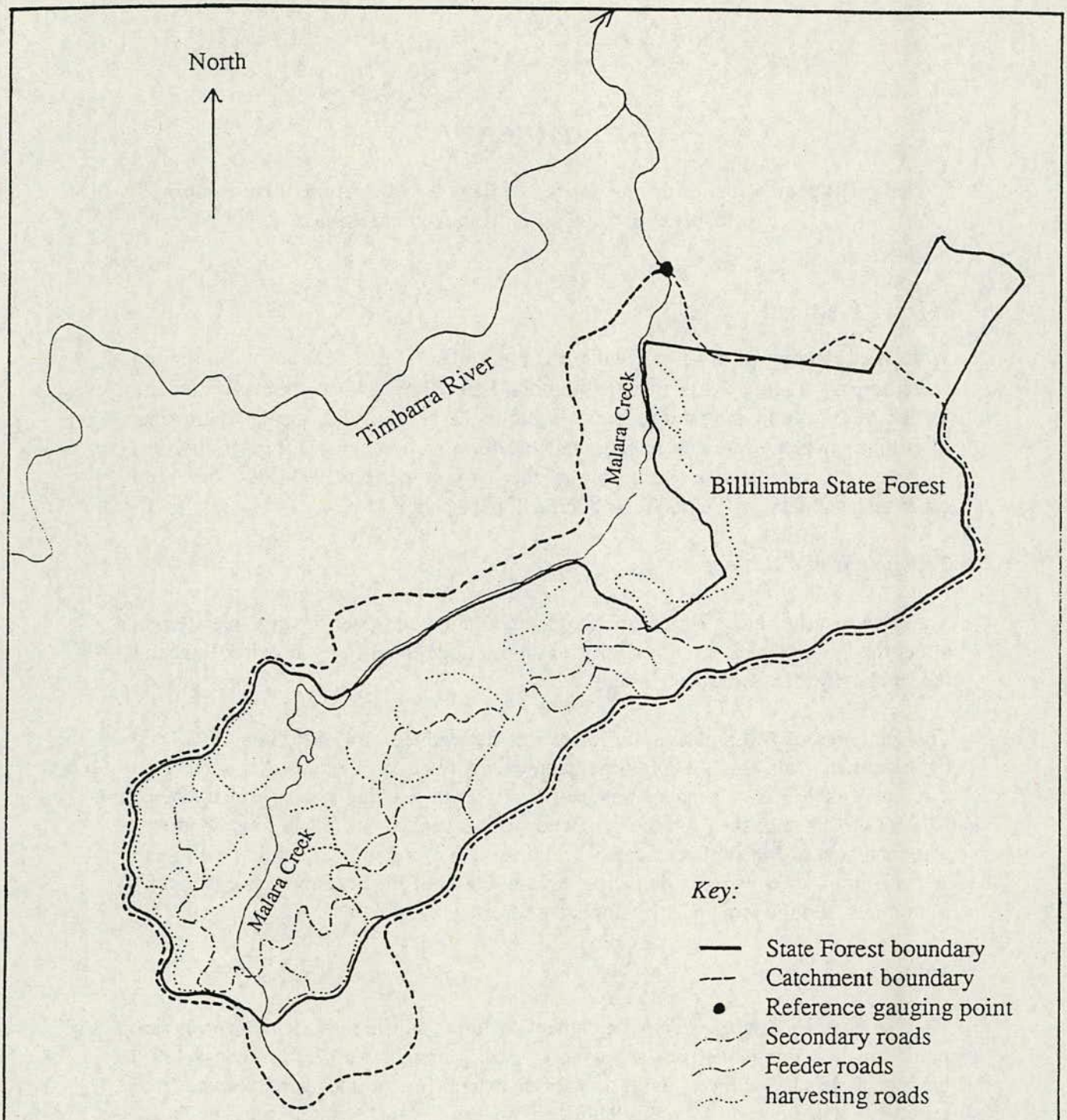
Soils

The soils of Malara Creek catchment within Billilimbra State forest are predominantly granite-derived sandy soils (Soil Mapping Unit D of Veness 1993) having stable surface layers, and, to a lesser extent, fine grained soils derived from eruptive volcanics (Soil Mapping Unit I in Veness 1993). A sample of Type D soil was collected alongside Malara Creek Fire Trail (Sample 2501 in Veness 1993) in the State forest. Typical particle size gradings for the surficial layer (A horizon) of Type D soils are clay (9%), silt (6%), fine sand (21%), coarse sand (21 %) and gravels (43 %).

As a group, Type D soils are stable but have a generally low to moderate erosion potential especially if they are disturbed and the lower horizons are exposed. Type I soils are also stable, having a low to moderate erosion potential.

Roads

Various existing fire trails are present in the catchment and some of these will be upgraded to forestry road standards. It is proposed to construct new roads as described in Table A1.



Scale: 1cm = 1 km

Figure A1 Malara Creek Section of Billilimbra State Forest showing proposed road network and drainage

Road lengths were determined from 1 : 25,000 series maps prepared by the FCNSW. The total area of the new road alignments is approximately 26 ha. which is 0.3% of the total area (7425 ha.) of Malara Creek catchment upstream of the gauging point (see Figure A1), and 0.4% of the area of Billilimbra State forest (5900 ha.)

Table A1

Total lengths of proposed new roads in the Malara Creek Section of Billilimbra State forest over the first 5-year period (1994-1999)

State forest	Road class	*Proposed (km)
Malara Creek Catchment	secondary roads	17.5
	feeder roads	17.5
	harvesting roads	37.0

* Determined approximately from Figure A1.

Safeguards

Standard Erosion Mitigation Guidelines for Logging (SEMGL) in NSW shall apply. The SEMGL guidelines are presented in the main report.

Most roads in the Malara Creek Section of Billilimbra State forest will follow the routes of existing fire trails, along ridge tops and contour lines. Thus sediment production will be significantly reduced than if new right-of-ways were constructed.

A2 Sediment Production

It is difficult to estimate with any accuracy the amount of sediment generated by road construction and harvesting operations; however, first pass conservative estimates can be made by making the following assumptions:

- From a literature review (Fahey & Coker 1992) of fine sediment generation from forest roads, an average of 2.3 kg/m^2/y to a maximum of 7 kg/m^2/yr (for fresh side cast fill) are typical for forest roads in hilly terrain and an annual rainfall of 1000 mm. A conservative value of 2 kg/m^2/yr has been adopted in the present study and takes account of the FCNSW adoption of Standard Erosion Mitigation Guidelines for Logging (SEMGL), road alignments following hill ridge lines, and the retention of buffer strips of natural vegetation along stream lines. The adopted value of 2 kg/m^2/yr is also in agreement with

the same rate of sediment production (20,000 kg/ha/yrÅ2 kg/m^2/yr) from road construction determined in Melbourne and Metropolitan Board of Works (MMBW) catchments by O'Shaughnessy & Jaysuriya (1987).

- Published rates of erosion from harvesting operations in the UK, especially in upland areas, range from 214 to 1300 kg/ha (Moffat 1991). Given the safeguards outlined in the SEMGL and the fact that avoidance of wet weather conditions is not practised in the UK, a conservative value of 500 kg/ha/yr has been adopted for subsequent calculations in the absence of published Australian data.

- Averages of size gradings for all Type D and Type I surficial soil samples revealed that the clay/silt/very fine sand component (<125 µm) is around 20% and 35%, respectively. The <125 µm size fraction has been assumed to be 25%, taking account of weighting of Type D soils which dominate in the Malara Creek catchment. Particle sizes less than 125 µm diameter are assumed to report to the natural drainage as suspended load and be transported downstream.

- Conservative estimates of sediment production assume that no natural or artificial revegetation of exposed surficial soils takes place.

Estimates are made in Table A2 for the quantities of sediments generated by road construction and harvesting operations which will be the main sources of sediments entering the natural drainage. The first 5 years of forestry operations in Billilimbra State forest have been detailed, as this is the principal period of combined road construction and harvesting operations.

Road Construction-derived Sediment Estimates

Table A2 gives an annual estimate of 102 tonnes/year (t/yr) for total sediment generated and entering surface drainage during the first 5 years of road construction in the Malara Creek Section of Billilimbra State forest. Of this total, the coarse sediment fraction (>125 µm) and very fine sediment fraction (<125 µm) are predicted to amount to 77 t/yr and 25 t/yr over the same five year period. The 25-t fine sediment production value is used in further calculations to estimate concentrations of suspended sediments in Malara Creek, at a point downstream of the State forest (see Figure A1).

Harvesting-derived Sediment Estimates

A harvesting rate of approximately 280 ha/yr is planned for the 10-year period (1994-2004) period of operations in Billilimbra State forest (FCNSW, Ron Fussell, pers. comm.).

Table A2 gives an annual estimate of 140 t/yr for total sediment generated annually and potentially entering the natural drainage. Of this total, the coarse sediment fraction (>125 µm) and very fine sediment fraction (<125 µm) are predicted to amount to 105 t/yr and 35 t/yr, respectively. The 35-t/yr fine sediment production value is used in further calculations to estimate concentrations of suspended sediments in Malara Creek, at a point downstream of the Billilimbra State forest.

A3 Total Suspended Sediment Loads

The proportion of total sediment entering and reporting as suspended sediment during the first 5 years of forestry operations has been estimated in Table A2 to be 60 tonnes/year. In order to predict total suspended sediment concentrations in Malara Creek, the following assumptions have been made:

- Exceedence flow duration data for Malara Creek have been estimated by the catchment area/ratio method using Department of Water Resources flow duration data for Washpool Creek which is located a few kilometres to the south of Billilimbra State forest and has a similar steep terrain and rainfall environment.

  Flow estimates for Malara Creek at the reference gauging point (see Figure A1) are 218 ML/d (Å2.5 m^3/s), 29 ML/d (Å0.3 m^3/s) and 8.6 ML/d (Å0.1 m^3/s) for the 10%, 50% and 90% exceedence flows, respectively. The 10%, 50% and 90% exceedence flow represent high, median and low flows respectively.

- Particles sizes less than 125 µm diameter are assumed to report to the natural drainage as suspended load and remain thus.

- It is assumed that the bulk of road-derived sediments will enter the natural drainage during high rainfall events, thus 90% is assumed to be mobilised and at high flows (10% exceedence flow) and the remaining 10% at median (50% exceedence flows). Little or no sediment is expected to report to the natural drainage during base or low flows (>90% exceedence flows).

- Concentrations of total suspended solids (TSS) in Malara Creek at a point immediately downstream of Billilimbra State forest (see Figure A1) have been predicted by diluting the annual tonnage of very fine sediments (<125 µm) into the estimated high and median flows at this reference gauging point.

- Background concentrations of TSS in Malara Creek have been estimated at 5 mg/L for median flow, 20 mg/L for high flow and 1 mg/L for low flow.

Predicted Total Suspended Sediment Concentrations

Table A3 predicts combined road construction- and harvesting-derived TSS concentrations in Malara Creek downstream of Billilimbra State forest under high, median and low flows. Tables A4 and A5 give separate predicted TSS concentrations imposed by road construction and harvesting operations.

Table A2

Estimates of sediment tonnages generated in first 5 years by road construction and harvesting operations in Malara Creek Section of Billilimbra State forest (1994-1999)

Source	Length (km)	*Width (m)	Total area (ha)	Annual rate (ha/yr)	Annual sediment generated: Total (t/yr)	>125µm (t/yr)	<125µm (t/yr)
Road Construction (1994-1999):							
Secondary road	17.5	4.2	7.35	1.47	29	22	7
Feeder roads	17.5	4.2	7.35	1.47	29	22	7
Harvesting roads	37	3.0	11.10	2.22	44	33	11
				Annual rate =	102	77	25
				Total (5 yrs) =	510 t	385 t	125 t
Harvesting Operations (1994-1999):			†280 ha/yr		140	105	35
				Annual rate =	140	105	35
				Total (5 yrs) =	700 t	525 t	175 t
Annual Total Sediment Production =					**242**	**182**	**60**

* Formation width

† FCNSW, Ron Fussell, pers. comm.

Reference to Table A3 reveals that under median flow conditions represented by 50% exceedence flow, annual TSS concentrations are expected to increase by 1 mg/L (20%) from 5 mg/L to 6 mg/L during the first 5 years of combined road construction and harvesting operations. At high flows, when most fine sediments will be mobilised, TSS concentrations in Malara Creek are expected to increase by 7 mg/L (35%) from an estimated background level of 20 mg/L to 27 mg/L. No anticipated increases in TSS concentrations are expected at base and low flows (90% exceedence flow).

Table A3

Predicted Total Suspended Sediment (TSS) concentrations in Malara Creek at a point downstream of Billilimbra State forest arising from the combined road construction and harvesting operations.

Station		Flow Exceedence High (10%E)	Median (50%E)	Low (10%E)
Malara Creek (downstream of Billilimbra State forest)	Flow (m^3/s)	2.5	0.3	0.1
	BSS (mg/L)	20.0	5.0	1.0
	FSS (mg/L)	7.0	1.0	0.0
	TSS (mg/L)	27.0	6.0	1.0

Notes: 10%E = 10% exceedence flow
50%E = 50% exceedence flow
90%E = 90% exceedence flow
BSS = Background Suspended Sediments
FSS = Forestry-derived Suspended Sediments
TSS = Total Suspended Sediments (BSS+FSS)

Table A4

Predicted annual Total Suspended Sediment (TSS) concentrations in Malara Creek at a point downstream of Billilimbra State forest arising from road construction

Station		Flow Exceedence High (10%E)	Median (50%E)	Low (10%E)
Malara Creek (downstream of Billilimbra State forest)	Flow (m^3/s)	2.5	0.3	0.1
	BSS (mg/L)	20.0	5.0	1.0
	RSS (mg/L)	3.0	0.5	0.0
	TSS (mg/L)	23.0	5.5	1.0

Notes: 10%E = 10% exceedence flow
50%E = 50% exceedence flow
90%E = 90% exceedence flow
BSS = Background Suspended Sediments
RSS = Road-derived Suspended Sediments
TSS = Total Suspended Sediments (BSS+RSS)

Table A5

Predicted annual Total Suspended Sediment (TSS) concentrations in Malara Creek at a point downstream of Billilimbra State forest arising from harvesting operations.

Station		Flow Exceedence High (10%E)	Median (50%E)	Low (10%E)
Malara Creek (downstream of Billilimbra State forest)	Flow (m^3/s)	2.5	0.3	0.1
	BSS (mg/L)	20.0	5.0	1.0
	HSS (mg/L)	4.0	0.5	0.0
	TSS (mg/L)	24.0	5.5	1.0

Notes: 10%E = 10% exceedence flow
50%E = 50% exceedence flow
90%E = 90% exceedence flow
BSS = Background Suspended Sediments
HSS = Harvesting-derived Suspended Sediments
TSS = Total Suspended Sediments (BSS+HSS)

Attachment B

Sediment Production Estimates for the Moratorium Area of Mount Marsh State Forest in the Casino Management Area

B1 General

A detailed roading plan was examined for the Moratorium Area of Mount Marsh State forest. Figure B1 shows Mount Marsh State forest, local drainage and the location of the proposed new roading. The annual rate of harvesting proposed in the State forest is estimated at 600 ha/yr (FCNSW, Ron Fussell, pers.comm.) and mainly in the 4-year period 1994 to 1998.

Topography and Drainage

The terrain in the catchment of the Moratorium Area is mostly steep and hilly, rising to 552 m at Mount Neville, 416 m at Bluff Mountain and 468 m at Dobie Mountain.

The total area of the Moratorium Area was determined as 3300 ha. as estimated by planimetry of a 1:100,000 topographic survey map. The Moratorium Area contains the headwater catchments of three streams, namely, Six Mile Creek, Batten's Bight Creek and Barrett's Creek . Their catchment areas were determined upstream of the reference gauging points shown in Figure B1, at which predicted concentrations of suspended sediments were calculated. The catchment areas of the three streams are approximately 2000 ha (61%) for Six Mile Creek, 700 ha (21%) for Batten's Bight Creek, and 600 ha (18%) for Barrett's Creek.

Soils

The soils of Six Mile Creek catchment within the Moratorium Area are predominantly Kangaroo Creek sandstones soils (Soil Mapping Unit F of Veness, 1993) being stable and of low erosion potential. The soils along the valleys of Six Mile Creek an its major tributaries within the Moratorium Area are alluvial-derived soils (Soil Mapping Unit A of Veness, 1993) with a low erosion potential in the upper layers and a low to moderate erosion potential in the lower horizons.

The soils of the Batten's Bight Creek catchment of the Moratorium Area have developed on the Kangaroo Creek Sandstones (Soil Mapping Unit F of Veness, 1993), having the aforementioned stability and erosion potential. The soils of the Barrett's Creek catchment have developed on the Walloon Coal Measures (Soil Mapping Unit G in Veness, 1993) and are stable with a low erosion potential.

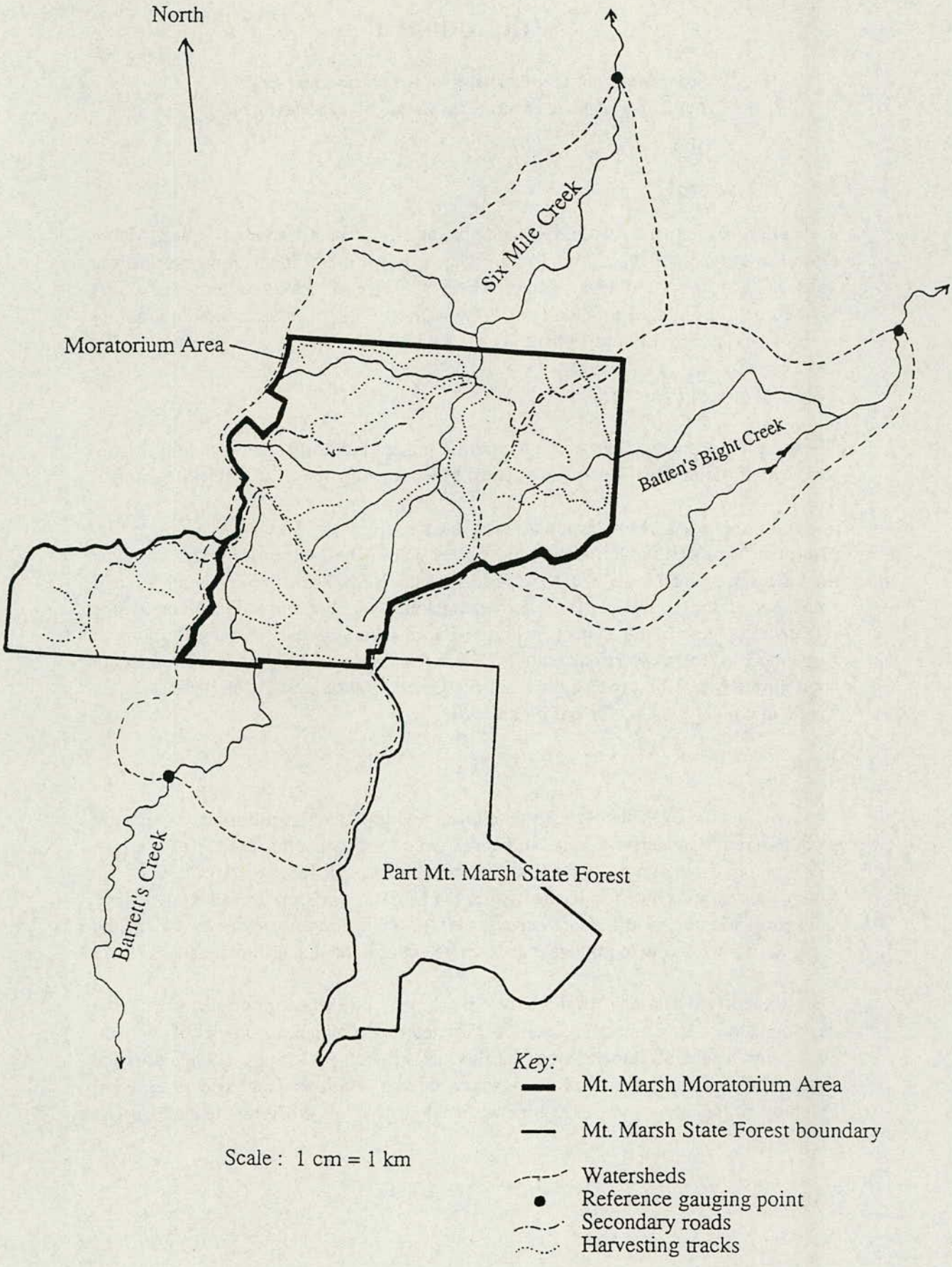


Figure B1 **Mt. Marsh State Forest and Moratorium Area showing proposed road network and drainage**

Roads

Various existing fire trails are present in the Moratorium Area and some of these will be upgraded to forestry road standards. It is proposed to construct new roads as described in Table B1 over a 2-year period (1994 and 1995). Road lengths were determined from 1:25,000 series maps prepared by the FCNSW. The total area of the new road alignments is approximately 14 ha. which is 0.4% of the total area (3300 ha.) of the Moratorium Area.

Table B1

Total lengths of proposed new roads in stream catchments of the Moratorium Area of Mount Marsh State forest in the CMA during the 2-year period (1994 and 1995)

Catchment	Road class	*Proposed (km)
Six Mile Creek	secondary roads	7.8
	harvesting roads	17.5
Batten's Bight Creek	secondary roads	2.8
	harvesting roads	6.3
Barrett's Creek	secondary roads	1.8
	harvesting roads	6.3

* Determined from Figure B1.

Safeguards

Standard Erosion Mitigation Guidelines for Logging (SEMGL) in NSW shall apply. The SEMGL guidelines are presented in the main EIS report.

Most roads in the Moratorium Area will follow the routes of existing fire trails, along ridge tops and contour lines. Thus sediment production will be significantly reduced than if new right-of-ways were constructed.

B2 Sediment Production

It is difficult to estimate with any accuracy the amount of sediment generated by road construction and harvesting operations; however, first pass conservative estimates can be made by making the following assumptions:

- From a literature review (Fahey & Coker 1992) of fine sediment generation from forest roads, an average of 2.3 kg/m^2/y to a maximum of 7 kg/m^2/yr (for fresh side cast fill) are typical for forest roads in hilly terrain and an annual rainfall of 1000 mm. A conservative value of 2 kg/m^2/yr has been adopted in the present study and takes account of the FCNSW adoption of Standard Erosion Mitigation Guidelines for Logging (SEMGL), road alignments following hill ridge lines, and the retention of buffer strips of natural vegetation along stream lines. The adopted value of 2 kg/m^2/yr is also in agreement with the same rate of sediment production (20,000 kg/ha/yrÅ2 kg/m^2/yr) from road construction determined in Melbourne and Metropolitan Board of Works (MMBW) catchments by O'Shaughnessy & Jaysuriya (1987).

- Published rates of erosion from harvesting operations in the UK, especially in upland areas, range from 214 to 1300 kg/ha (Moffat 1991). Given the safeguards outlined in the SEMGL and the fact that avoidance of wet weather conditions is not practised in the UK, a conservative value of 500 kg/ha/yr has been adopted for subsequent calculations in the absence of published Australian data.

- Averages of the clay/silt very fine sand component (<125 µm size fraction) for different soils of the Moratorium Area have been estimated for the main catchments:

  - *Six Mile Creek Catchment:* The clay/silt/very fine sand component (<125 µm size fraction) of the prevailing Type F and Type A soils are around 20% and 30%, respectively. The <125 µm size fraction for both soil types has been averaged and a <125 µm size fraction of 25% assumed for further calculations.

  - *Batten's Bight Creek Catchment:* The clay/silt/very fine sand component (<125 µm size fraction) of the prevailing Type F soils is around 20%.

  - *Barrett's Creek Catchment:* The clay/silt/very fine sand component (<125 µm size fraction) of the prevailing Type G soils is around 40%.

- The estimates of sediment production are conservative as it is assumed that no natural or artificial revegetation of exposed surficial soils takes place in tfeh short term.

Estimates are made in Table B2 for the quantities of sediments generated by road construction and harvesting operations which will be the main sources of sediments entering the natural drainage. The first 2 years of forestry operations in the Moratorium Area of Mount Marsh State forest have been detailed, as this is the principal period of combined road construction and harvesting operations.

Road Construction-derived Sediment Estimates

Annual road construction-derived estimates of sediment production are given in Table B2 for the catchments of the three streams that drain the Moratorium Area of Mount Marsh State forest.

Table B2 gives an annual estimate of 86 tonnes/year (t/yr) for total sediment generated and entering surface drainage in Six Mile Creek catchment during the first 2 years of road construction in the Moratorium Area of Mount Marsh State forest. Of this total, the coarse sediment fraction (>125 µm) and very fine sediment fraction (<125 µm) are predicted to amount to 65 t/yr and 21 t/yr over the same five year period. Annual total sediment production in the catchments of Batten's Bight Creek and Barrett's Creek are 31 t/yr and 27t/yr respectively (see Table B2). The very fine sediment production values are used in further calculations to estimate concentrations of suspended sediments in the three streams draining the Moratorium Area.

Harvesting-derived Sediment Estimates

An annual harvesting rate of approximately 600 ha/yr is planned in the Mount Marsh State forest. An estimate of the harvesting rate in the Moratorium Area has been calculated to be approximately 260 ha/yr, based on the Moratorium Area (3300 ha) being 44% of th etotal area of Mount Marsh State forest (7553 ha).

Estimates of annual harvesting rates in the three catchments of the Moratorium Area were derived on an area basis (Table B2). In Six Mile Creek catchment, annual total sediment production from harvesting operations is estimated at 75 t/yr, comprised of 56 t/yr of coarse sediment (>125 µm) and 19 t/yr of very fine sediment (<125 µm). A breakdown of sediment production arising from harvesting operations in the catchments of Batten's Bight and Barrett's Creeks in the Moratorium Area is given in Table B2.

B3 Total Suspended Sediment Loads

In order to predict total suspended sediment concentrations in the three streams with catchments in the Moratorium Area, the following assumptions have been made:

- Exceedence flow duration data for Six Mile, Batten's Bight and Barrett's Creeks have been estimated by the catchment area/ratio method using Department of Water Resources flow duration data for Gorge Creek (catchment area = 4350 ha) which drains Richmond Range State forest 70 km kilometres to the north of Mount Marsh State forest, and has a similar steep terrain and rainfall environment. Flow duration estimates for the three streams are given below:

Table B2

Estimates of annual sediment tonnages generated during the 2-year period (1994-1995) of road construction and harvesting operations in the Moratorium Area of Mount Marsh State forest

Source	Length (km)	*Width (m)	Total area (ha)	Annual rate (ha/yr)	Annual sediment generated: Total (t/yr)	>125µm (t/yr)	<125µm (t/yr)
Road Construction (1993-1995):							
Six Mile Creek catchment:							
Secondary road	7.8	4.2	3.28	1.64	33	25	8
Harvesting roads	17.5	3.0	5.25	2.63	53	40	13
				Annual rate =	86	65	21
				Total (2 yrs) =	172 t	130 t	42 t
Batten's Bight Creek catchment:							
Secondary road	2.8	4.2	1.18	0.60	12	10	2
Harvesting roads	6.3	3.0	1.89	0.94	19	15	4
				Annual rate =	31	25	6
				Total (2 yrs) =	62 t	50 t	12 t
Barrett's Creek catchment:							
Secondary road	1.8	4.2	0.76	0.38	8	5	3
Harvesting roads	6.3	3.0	1.89	0.94	19	11	8
				Annual rate =	27	16	11
				Total (2 yrs) =	54 t	32 t	22 t
Harvesting Operations (Annual rate):							
(Whole Moratorium Area Å†260 ha/yr)							
Six Mile Creek catchment (2000 ha)				150 ha/yr	75	56	19
Batten's Bight Creek catchment (700 ha)				50 ha/yr	25	19	6
Barrett' s Creek catchment (600 ha)				45 ha/yr	23	17	6
Annual Total Sediment Production in Moratorium Area =					**267**	**198**	**69**

* Formation width

- Six Mile Creek (4300 ha): Flow estimates at the reference gauging point (see Figure B1) are 32.4 ML/d (Å0.375 m^3/s), 2.9 ML/d (Å0.034 m^3/s) and 0.001 ML/d (<0.0001 m^3/s) for the 10%, 50% and 90% exceedence flows, respectively.

- Batten's Bight Creek (2675 ha): Flow estimates at the reference gauging point (see Figure B1) are 20.3 ML/d (Å0.235 m^3/s), 1.8 ML/d (Å0.021 m^3/s) and 0.001 ML/d (<0.0001 m^3/s) for the 10%, 50% and 90% exceedence flows, respectively.

- Barrett's Creek (2100 ha): Flow estimates at the reference gauging point (see Figure B1) are 15.7 ML/d (Å0.182 m^3/s), 1.4 ML/d (Å0.016 m^3/s) and 0.001 ML/d (<0.0001 m^3/s) for the 10%, 50% and 90% exceedence flows, respectively.

- Particles sizes less than 125 µm diameter are assumed to report to the natural drainage as suspended load and remain thus.

- It is assumed that the bulk of road- and harvesting-derived sediments will enter the natural drainage during high rainfall events, thus 90% is assumed to be mobilised and at high flows (10% exceedence flow) and the remaining 10% at median (50% exceedence flows). Little or no sediment is expected to report to the natural drainage during base or low flows (>90% exceedence flows).

- Concentrations of total suspended solids (TSS) in the three streams draining the Moratorium Area (Six Mile, Batten's Bight and Barrett's Creeks) at a reference gauging points immediately downstream of the Area (see Figure B1) have been predicted by diluting the annual tonnage of very fine sediments (<125 µm) into the estimated high and median flows at this reference gauging point.

- Background concentrations of TSS in the three streams have been assumed to be the same and have been estimated at 5 mg/L for median flow (50% exceedence), 20 mg/L for high flow (10% exceedence) and 1 mg/L for low flow (90% exceedence). These low values are typical for streams draining forested catchments in the CMA.

- An estimate of the annual harvesting rate in the Moratrorium Area has been assumed at around 260 ha/yr based on the Moratorium Area (3300 ha) being 44% of the total area of Mount Marsh State forest (7553 ha).

- Estimates of annual harvesting rates in the catchments of the three streams draining the Moratorium Area have been estimated by proportion:

  - *Six Mile Creek catchment (2000 ha):* 61% of Moratorium Area; therefore, annual harvesting rate is estimated at 150 ha/yr.

  - *Batten's Bight Creek catchment (700 ha):* 21% of Moratorium Area; therefore, annual harvesting rate is estimated at 50 ha/yr.

  - *Barrett's Creek catchment (600 ha):* 18% of Moratorium Area; therefore, annual harvesting arate is estimated at 45 ha/yr.

Predicted Total Suspended Sediment Concentrations

Table B3 predicts combined road construction- and harvesting-derived TSS concentrations in the three streams draining the Moratorium Area under high, median and low flows. Tables B4 and B5 give separate predicted TSS concentrations imposed by road construction and harvesting operations.

Considering the main stream draining the Moratorium Area (Six Mile Creek), Table B3 reveals that under median flow conditions represented by the 50% exceedence flow, annual TSS concentrations are expected to increase by 7 mg/L (140%) from 5 mg/L to 12 mg/L during the first 2 years of forestry operations. At high flows, when most fine sediments will be mobilised, TSS concentrations in Six Mile Creek are expected to increase by 30 mg/L (150%) from an estimated background level of 20 mg/L to 50 mg/L. No significant increases in TSS concentrations are expected at base and low flows (90% exceedence flow). In both Batten's Bight and Barrett's Creeks, TSS concentrations at median flows are expected to increase by 80% and 140% respectively. The larger increase of forestry-imposed suspended loads in Barrett's Creek catchment is due to the prevalence of Type G soils, which have a higher percentage of particles in the clay/silt/very fine sands size range.

It should be noted that the predicted concentrations of suspended sediments in the three streams draining the Moratorium Area are conservative estimates. As road construction sites and other disturbed areas stabilise and revegetate, sediment sources will concomitantly reduce in time, and TSS concentrations in the streams are expected to rapidly decline towards background levels. The following features and prescriptions will also serve to minimise suspended sediment loading of the local drainage system:

- Sound application of SEMGL and Codes of Logging Practice.
- Maintenance of non-disturbed areas such as:
  - filter strips along creeks having catchments equal or greater than 30 ha.
  - presence of areas designated as inaccessible to harvesting
  - non-commercial areas.
  - P.M.P. 1.1.7 (Flora and Fauna Reserves) located along Batten's Bight, Six Mile and Barrett's Creeks within the Moratorium Area.

Table B3

Predicted annual Total Suspended Sediment (TSS) concentrations arising from combined road construction and harvesting operations in three streams draining the Moratorium Area of Mount Marsh State forest at a points downstream of the Area

Station		Flow Exceedence High (10%E)	Median (50%E)	Low (10%E)
Six Mile Creek (downstream of Moratorium Area)	Flow (m^3/s)	0.375	0.034	<0.0001
	BSS (mg/L)	20	5	1
	FSS (mg/L)	30	7	0
	TSS (mg/L)	50	12	1
Batten's Bight Creek (downstream of Moratorium Area)	Flow (m^3/s)	0.235	0.021	<0.0001
	BSS (mg/L)	20	5	1
	FSS (mg/L)	15	4	0
	TSS (mg/L)	35	9	1
Barrett's Creek (downstream of Moratorium Area)	Flow (m^3/s)	0.182	0.016	<0.0001
	BSS (mg/L)	20	5	1
	FSS (mg/L)	27	7	0
	TSS (mg/L)	47	12	1

Notes: 10%E = 10% exceedence flow
50%E = 50% exceedence flow
90%E = 90% exceedence flow
BSS = Background Suspended Sediments
FSS = Forestry-derived Suspended Sediments
TSS = Total Suspended Sediments (BSS+FSS)

Table B4

Predicted annual Total Suspended Sediment (TSS) concentrations arising from road construction in the three streams draining the Moratorium Area of Mount Marsh State forest at points downstream of the Area

Station		Flow Exceedence High (10%E)	Median (50%E)	Low (10%E)
Six Mile Creek (downstream of Moratorium Area)	Flow (m^3/s)	0.375	0.034	<0.0001
	BSS (mg/L)	20	5	1
	RSS (mg/L)	16	4	0
	TSS (mg/L)	36	9	1
Batten's Bight Creek (downstream of Moratorium Area)	Flow (m^3/s)	0.235	0.021	<0.0001
	BSS (mg/L)	20	5	1
	RSS (mg/L)	7	2	0
	TSS (mg/L)	27	7	1
Barrett's Creek (downstream of Moratorium Area)	Flow (m^3/s)	0.182	0.016	<0.0001
	BSS (mg/L)	20	5	1
	RSS (mg/L)	17	4.5	0
	TSS (mg/L)	37	9.5	1

Notes: 10%E = 10% exceedence flow
50%E = 50% exceedence flow
90%E = 90% exceedence flow
BSS = Background Suspended Sediments
RSS = Road-derived Suspended Sediments
TSS = Total Suspended Sediments (BSS+RSS)

Table B5

Predicted annual Total Suspended Sediment (TSS) concentrations arising from harvesting operations in three streams draining the Moratorium Area of Mount Marsh State forest at points downstream of the Area

Station		Flow Exceedence High (10%E)	Median (50%E)	Low (10%E)
Six Mile Creek (downstream of Moratorium Area)	Flow (m^3/s)	0.375	0.034	<0.0001
	BSS (mg/L)	20	5	1
	HSS (mg/L)	14	3	0
	TSS (mg/L)	34	8	1
Batten's Bight Creek (downstream of Moratorium Area)	Flow (m^3/s)	0.235	0.021	<0.0001
	BSS (mg/L)	20	5	1
	HSS (mg/L)	7	2	0
	TSS (mg/L)	27	7	1
Barrett's Creek (downstream of Moratorium Area)	Flow (m^3/s)	0.182	0.016	<0.0001
	BSS (mg/L)	20	5	1
	HSS (mg/L)	9	2.5	0
	TSS (mg/L)	29	7.5	1

Notes: 10%E = 10% exceedence flow
50%E = 50% exceedence flow
90%E = 90% exceedence flow
BSS = Background Suspended Sediments
HSS = Harvesting-derived Suspended Sediments
TSS = Total Suspended Sediments (BSS+HSS)