WATER RESOURCES

& MANAGEMENT

QUEENSLAND CRA/RFA STEERING COMMITTEE

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BUREAU OF RESOURCE SCIENCES

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SUMMARY

This report has been prepared for the joint Commonwealth/State Steering Committee which oversees the Comprehensive Regional Assessment (CRA) of forests in the South East Queensland CRA region.

The Comprehensive Regional Assessment provides the scientific basis on which the State and Commonwealth governments will sign a Regional Forest Agreement (RFA) for the forests of the South East Queensland CRA region. This agreement will determine the future of the region's forests and will define those areas needed to form a comprehensive, adequate and representative (CAR) reserve system and those available for ecologically sustainable commercial use.

This report is the result of an assessment of water supply and catchment management in South East Queensland forests. It is one part of a comprehensive assessment of these forests being undertaken as part of the process leading to a bilateral agreement between the Queensland and Commonwealth Governments in relation to the management and utilisation of the region's forests. Because one of the eleven broad goals of the National Forest Policy Statement is 'to ensure the availability of reliable, high-quality water supplies from forested land and to protect catchment values', catchment management is an important component of the assessment.

The primary objective of the hydrology study was: 'to compile data to describe the role, importance and sensitivities to forest uses of water yield and quality from forested catchments in South East Queensland.' It was a desk-based study of literature, data and information with inputs from various people, including stakeholders.

The region's forests are recognised as producing good quality water compared to other land uses in the catchments. However, the study revealed that there is a dearth of published information about the quality or the quantity of water yielded from these forests; although 'paired catchment' studies (studies that monitor and compare the environmental parameters of two adjacent catchments receiving different experimental treatments, such as selection logging and no logging treatments) have been set up to investigate the environmental effects of logging.

To date, the focus of research into forest hydrology in the region, has been on improving the operational systems of forest/plantation management to reduce soil erosion and improve local water quality. Consequently the development of operational management systems has been driven more by observational and experiential evidence than by quantitative scientific monitoring and analysis.

Current and future development of plantations on cleared agricultural land in South East Queensland may alter the hydrology of the region. In order to accurately predict what these effects may be, research on how new plantations affect local hydrology would be valuable, but requires funding and development to be undertaken.

In addition, constraints on the availability of unpublished data have limited the scope of this study. These constraints have been a function of a number of valid concerns by State agency officers, and is discussed in detail in section 3.1. In these circumstances, the assessment has provided the opportunity to identify and report on gaps in the knowledge available about forest hydrology in

the region, and make recommendations for research and development. Within this context, the report has attempted to address the potential and actual effects of forest management on catchment hydrology by taking a total catchment perspective.

Using this approach has made it possible to identify a number of relevant issues. Notably, government policy for the management of forests and plantations in the region requires the sustainable production of wood while protecting water, native forest and conservation values. For Department of Primary Industries - Forestry, protection of water values means principally the prevention and mitigation of erosion. In addition, land use changes of the past, especially clearing vegetation to convert land to agricultural purposes, continue to affect catchment hydrology by altering the water balance and (most likely) reducing water quality from its pre-settlement condition. This assessment indicates that there will be continuing, increasing pressure to develop the water resources of South East Queensland to meet the competing demands of a wide range of users, including growing city populations, agriculture and industry.

In this region, few water supply catchments are completely forested, but the forested parts are often the hydrologically significant headwaters of major rivers, where rainfall is highest. For example, native forests and hoop pine plantations are found in the upper catchment areas of the Brisbane and Mary Rivers, two of the most important rivers for water supply in South East Queensland.

Conclusions

From the assessment of hydrology, catchment and water values in South East Queensland, a number of conclusions can be drawn:

- South East Queensland is a rapidly growing and developing part of Australia with a diverse range of land uses.
- The region’s water resources will be under increasing pressure to meet the needs of a wide range of users, and the environment.
- Forests are recognised as producing good quality water compared to other uses of land in the region’s catchments.
- In terms of water quality, there is currently insufficient research available to gauge the effects of current forestry activities and practices.
- Government policy documents rarely consider the water requirements of the forestry sector.
- Few data are available on forest water yields and quality in South East Queensland, although paired catchment studies are now underway in both exotic pine plantations and native forest. Most of these studies are too recently established to have yielded results on water quality and quantity issues yet.
- In terms of water yield and town water supplies, forests and forestry activities are likely to be less important in South East Queensland than in many other regions of Australia because only a

small proportion of the region's town water supplies are derived from completely forested catchments.

- Research in the publicly owned estate in South East Queensland has been focused on improving the operational systems of forest or plantation management in order to reduce soil erosion and improve local water quality. The development of operational systems for these aspects of management has largely been driven by observational and experiential evidence. This focus has been acknowledged in recent research reports and recommendations have been made to improve soil and water quality management systems by continuing this adaptive learning framework and supporting current management with overt demonstrations (monitoring systems) of sustainability, including the development of key indicators to be used as the basis of the monitoring process.

Recommendations

Several priorities for research and development in the region have been identified:

- Publication of data from the Department of Primary Industries – Forestry's current hydrological studies;

- Develop a quantitative basis for the Department of Primary Industries – Forestry's soil and water protection practices, and improve these practices based on results obtained from quantitative research;

- Develop scientifically-based soil and water monitoring systems using indicators that are nationally compatible and accreditable. Refine existing operational management systems to include the identification of key indicators and the development of a program of monitoring and reporting against these indicators. The current process of developing criteria and indicators under the ecologically sustainable forest management process, as a part of the comprehensive regional assessments leading to regional forest agreements, and under the Montreal Process, are relevant to the development of regional indicators, and should be taken into account.

- Investigate the water yield/water quality effects of current forest and plantation management and consider the effects that the establishment of new plantations on cleared agricultural land may have. Findings of significant change should be assessed for water supply policy implications.

1. INTRODUCTION

1.1 GENERAL INTRODUCTION

The availability of reliable, high quality water and the protection of catchment values were identified jointly in the National Forest Policy Statement (1992) as one of eleven broad goals constituting the national vision for Australia's forests. The policy, agreed to by the Commonwealth Government and State and Territory Governments, is being implemented at the regional level. An assessment of hydrology, catchment and water values is therefore an important component of the broader assessment of forests in the South East Queensland region that is currently underway. This assessment process is one of a number of 'comprehensive regional assessments' (CRAs) taking place around Australia leading, in each case, to a 'regional forest agreement' (RFA). These agreements govern how the forests in each region will be managed and utilised. The assessments provide the information from which these bilateral agreements between the relevant State and the Commonwealth are developed.

The South East Queensland hydrology assessment focused, as far as possible, on information in published studies, as such studies have been subjected to peer review before publication and are easily found because they are on databases. Library searches and electronic 'key word' searches of titles and abstracts of scientific literature were undertaken to locate appropriate reports. However, it was also necessary to use information from unpublished reports, data or personal communications in order to cover the relevant issues comprehensively.

1.2 INTRODUCTION TO THE SOUTH EAST QUEENSLAND REGION

The South East Queensland region, for regional forest agreement purposes, covers about 6 million hectares of Queensland (Regional Forest Assessments - Department of Natural Resources data 1998). The region covers the southeastern corner of the State and is roughly defined by the New South Wales border in the south and by the city of Gladstone in the north. To the west it extends beyond Toowoomba and Monto. It also takes in the Blackdown Tableland area, an isolated outlier about 100 kilometres inland from Rockhampton. The region includes the major centres of Greater Brisbane, Bundaberg, Maryborough and Gympie and the extensively developed coastal areas of the Gold and Sunshine Coasts, as well as many smaller rural towns.

The region has a population of about 2.45 million people and covers 44 local government areas. Population growth is currently greatest in the coastal and hinterland areas, especially on the fringes of Brisbane and in the areas of the Gold Coast, Sunshine Coast and Hervey Bay. In the rural areas in the west, population is generally declining or undergoing low growth (South East Queensland RFA information kit 1997). Land uses in the region are diverse, with urban areas, rural and agricultural areas. Forests cover about 44% per cent of the region's 6 086 497 hectares. Privately owned forests cover about 20% of the region. About 15% of the area is State forest and national parks cover about 8% (Regional Forest Assessments - Department of Natural Resources data 1998).

Water is a valuable resource for all land users, and for the environment. The region's water catchments provide domestic supplies for a number of large urban communities and numerous rural communities and for the Bundaberg and Lower Mary River Irrigation Areas. In addition, water within the region carries ecological and social values.

A reliable supply of water that meets quality standards for domestic, agricultural, industrial and recreational uses is essential. However, water yield and quality are sensitive to changes both in land cover and in management practices affecting land use in catchments, making the relationship between water, land cover and land use complex. This relationship is based on extrinsic factors such as climate, geology, soils, and topography as well as intrinsic factors such as land cover change.

This report addresses the potential and actual effects of forest management on catchment hydrology by taking a total catchment perspective. An overview of water resources and uses is given, including an assessment of the relationship between land use and water values. Background information is provided on land tenure and use and regional characteristics such as climate, topography, geology, hydrogeology, soils, vegetation and aquatic ecosystems. This contextual approach emphasises the links between systems and processes and permits identification of potentially hazardous or high risk areas.

1.2.1 Climate

South East Queensland has a humid sub-tropical climate with mild winters and warm summers. December and January are the hottest months. Most rain occurs in summer, a result of convective storms associated with low pressure troughs that extend southwards from north Australia. Winter rain is associated with the passage of cold fronts extending northwards from mid-latitude depressions. Prevailing winds are from the west or south-west in the winter, but occasionally the development of low pressure systems off the coast produces an inflow of moist air from the east. July is the coolest month when the mean daily temperature may drop below 10^{o} C. Although there is less cloud in winter than in summer, the risk of frosts is limited to coastal areas. Fogs are more frequent in winter. In Brisbane, for instance, the August average for foggy days is 3.6. Table 1.2.1 gives a summary of climatic data for major centres in the region.

TABLE 1.2.1 climate

Town	Rainfall (mm)				Temperature (^{o}C)				Mean 3 pm relative. humidity (%)	
	Annual mean	Jan. mean	July mean	Wet days p/a	Jan daily max.	Jan daily min.	July daily max.	July daily min.	Jan.	Jul.
Brisbane	1188	162	63	122	29.2	21.0	20.6	9.4	59	47
Bundaberg	1040	190	46	104	29.6	21.3	21.6	9.8	62	49
Maryborough	1166	167	54	118	30.7	20.6	21.9	8.5	59	49
Toowoomba	960	136	54	107	27.6	16.6	16.3	5.2	55	51
Gympie	1139	166	55	116	31.3	19.5	21.9	6.3	56	46

Source: Bureau of Meteorology Statistics (1997).

1.2.2 Topography

In general terms, the topography of South East Queensland comprises a coastal zone characterised by large areas of sand ridges, estuarine tracts and undulating lowlands of less than 120 metres elevation. Isolated peaks of low to moderate relief occur near the coast and include the Glass House Mountains. In the west, hilly to mountainous country, part of the Great Dividing Range, trends north-northwesterly. High peaks include West Barney Peak (1359 metres) near the border with New South Wales; Mount Mistake (1092 metres) south-east of Toowoomba, and Mount Kiangarow (1146 metres) in the Bunya Mountains National Park, west of Nanango. The trend of these mountain ranges is determined by major geological structures (such as folds), and the orientation of major drainage systems corresponds with faults. Drainage patterns are also geologically controlled, with secondary drainage lines aligning with joints in granitic and volcanic rocks. Further west and north, landforms comprise moderate relief and plateaus including the Darling Downs.

1.2.3 Geology

The oldest rocks of the region comprise undifferentiated Palaeozoic rocks as deeply weathered siltstones, shales, greywackes and limestone. These have been intruded by Permo-Triassic granitoid rocks as granite, granodiorite, adamellite and diorite. These intrusions trend north-northwesterly and occur as outcrops at Miriam Vale and Mount Perry, west of Bundaberg, and as large batholiths in the districts of Kingaroy, Wondai and Camboon.

Permian and Triassic volcanics and interbedded sandstones and shales occur along the north-eastern edge of the region and near Gympie and Nambour. These rocks form resistant ridges trending north-northwesterly and comprise volcanic agglomerate, acid tuff, rhyolite and trachyte. These rocks are similar in age to that of sediments deposited in basins on the western margins of the Fold Belt, which include economic coal deposits at Ipswich, Callide and Tarong.

During the Triassic-Jurassic, continental sediments were deposited in a number of basins located in the western and eastern sections of the region. To the west, these basins comprise fossiliferous sandstones, shales and carbonaceous shales with economic coal deposits. The basins on the eastern edge of the region comprise Jurassic continental sediment as fossiliferous sandstones, siltstones and shales with lenses of carboniferous shale.

Basaltic and rhyolitic flows and tuffs, as a result of Tertiary volcanic activity, form remnants of a large volcanic complex whose crater was above the present Mt. Warning igneous complex just south of the Queensland–New South Wales border. These volcanics consist of flat-topped spurs radiating to the north-west, north and north-east, separated by deeply incised valleys. These Tertiary lavas form the Great Dividing Range between the border with New South Wales and Kingaroy in the north, and make up the coastal lowlands in the vicinity of Maroochydore and Coolangatta.

Tertiary sediments are associated with the volcanics and occur as interbedded sequences of soft mudstones, sandstones, lignite and coarse conglomerate.

The Quaternary unconsolidated sediments occur as coastal sand plains and dunes, and as alluvium associated with the main drainage systems inland.

1.3 LAND USE

Land use in the region is diverse and includes urban and industrial areas, forestry in native forests and plantations, national parks, and dryland and irrigated production of sugar, dairy, beef, grain, fruit and vegetables.

Substantial areas of native vegetation have been cleared to make way for agriculture. Such large-scale, permanent clearing changes catchment hydrology. The effects can include increased water yield and a possible increase in the severity of floods (Cassells 1984). In addition, numerous dams and weirs have been built in the region to meet the demands for water for urban supplies and agricultural and industrial use and to provide for flood control, hydro-electricity production and recreation. These constructions may compound changes made by clearing.

Wastes such as human and animal wastes, silt, nutrients, pesticides, mining and industrial waste products may affect water quality if they enter streams or groundwater.

The overall result of land use change since European settlement has been that water quality and quantity and the natural flow regimes of many streams in South East Queensland have been significantly altered from their pre-European condition (Department of Primary Industries 1993). Population growth and urban expansion is continuing, which will result in further land use change and more pressures on South East Queensland's water resources (Department of Primary Industries 1993).

There are about 2.7 million hectares of forest in the South East Queensland region, which means that slightly less than half the region is forested. About 44% of these forests are privately owned, about 31% are State forests and about 13% are in national parks (Regional Forest Assessments - Department of Natural Resources data 1998). There are 178 361 hectares of plantations in the region, about 7% of the total forest area (Regional Forest Assessments - Department of Natural Resources data 1998).

Grazing occurs in a significant proportion of Queensland's native forest and plantations under special lease or grazing permits (Government of Queensland 1990). Queensland's State forests are designated as multiple land use areas. In addition to wood production, uses include grazing, apiculture, harvesting of comparatively minor forest products, quarrying, and recreation. State forests includes both native forest and plantations. In the South East Queensland region, about 90% of plantations are part of State forests.

National parks are a different tenure to State forests, and apiculture, quarrying and harvesting of minor products are not permitted. Grazing may still occur (a legacy of previous land tenure) but is gradually being phased out (Government of Queensland 1990).

A description of the catchment hydrology of the region is made complex by the mix of tenures and variety of land uses permissible within and between tenures. Table 1.3.1 details the size of the forested area in each tenure in the region.

TABLE 1.3.1 AREA OF LAND BY TENURE WITHIN THE SOUTH EAST QUEENSLAND REGION

Tenure Class	Broad Forest Type/Grouping									
	Native Forest		Plantation		Total Forest		Non Forest		Total	
	Area (ha)	% Total Area	Area (ha)	% Total Area	Area (ha)	% Total Area	Area (ha)	% Total Area	Area (ha)	% Total Area
Freehold (Private)	1 191 300	19.57	15 775	0.26	1 207 075	19.83	3 070 273	50.44	4 277 348	70.28
Nature Conserv.	357 507	5.87	497	0.01	358 004	5.89	127 594	2.10	485 598	7.98
Other Crown Land	274 325	4.51	2 517	0.04	276 842	4.55	133 954	2.20	410 796	6.75
State Forest	688 898	11.32	159 442	2.62	848 340	13.94	40 427	0.66	888 767	14.60
Timber Reserves	23 695	0.39	131	0.00	23 826	0.39	162	0.00	23 988	0.39
Total	2 535 726	41.66	178 361	2.93	2 714 087	44.59	3 372 410	55.4	**6 086 497**	100.00

Source: Regional Forest Assessments - Department of Natural Resources data 1998.
Note: Total Forest means native forest plus plantation

1.4 WATER RESOURCES

Surface water refers to rivers and lakes, groundwater refers to the below ground water resources. Currently 44% of Queensland's domestic and industrial water supplies come from groundwater aquifers (Water Infrastructure Task Force 1997). Therefore, it is important to consider groundwater in the context of total water supply for Queensland.

1.4.1 Surface water

The Australian Water Resources Council has divided Australia into 12 drainage divisions that are subdivided into river basins. The South East Queensland region contains part of two drainage divisions, No. 1 – North-East Coast, and No. 4 – Murray-Darling.

Within the divisions there are a number of river basins wholly within the region and several basins partly within the region. The following basins are wholly within the region:

Baffle Creek Basin (#134);

Boyne River Basin (#133), including Boyne River tributaries;

Brisbane River Basin (#143), including the Brisbane, Bremer and Stanley Rivers and their tributaries;

Burrum River Basin (#137), including the Burrum, Elliott, Gregory and Isis Rivers and their tributaries;

Fraser Island Basin (#139);

Logan-Albert Rivers Basin (#145), including the Albert, Burnett and Logan Rivers and their tributaries;

Kolan River Basin (#135), including Kolan Rivertributaries;

Maroochy River Basin (#141)including the Mooloolah, North Maroochy and South Maroochy Rivers and their tributaries;

Mary River Basin (#138), including Mary River tributaries;

Noosa River Basin (#140), including Noosa River tributaries;

Pine River Basin (#142), including the North Pine and South Pine Rivers and their tributaries;

South Coast Basin (#146), including the Broadwater, Coomera, and Nerang Rivers and their tributaries; and

Stradbroke Island Basin (#144);

The region also contains parts of river basins that extend beyond the region, including the Calliope River Basin (#132); Fitzroy River Basin (#130); Burnett River Basin (#136), and Condamine-Culgoa Rivers Basin (#422).

Surface water resources and drainage characteristics of these basins are provided in Appendix 1. Table 1.3.2 gives details of the tenure of the land in each basin in the region.

TABLE 1.3.2 AREA OF LAND WITHIN EACH TENURE CATEGORY FOR EACH AWRC BASIN IN THE SOUTH EAST QUEENSLAND REGION

AWRC Basin name	Multiple Use Forest (ha)	Nature Conservation Areas (ha)	Water Production (ha)	Other Crown Land (ha)	Private Freehold (ha)	Reserved Crown Land (ha)	No data (slivers) (ha)	Total (ha)
Baffle Creek	47 000	26 000		1 000	319 000	1 000	1 000	395 000
Boyne River	29 000	7 000			142 000	1 000		179 000
Brisbane River	151 000	16 000	21 000		1 134 000	2 000	2 000	1 326 000
Burnett River	150 000	8 000			1 106 000	2 000	1 000	1 267 000
Burrum River	90 000	23 000			219 000	1 000	2 000	335 000
Calliope River	9 000				20 000			29 000
Condamine-Culgoa Rivers	11 000	7 000			34 000			52 000
Curtis Island	7 000				20 000			27 000
Fitzroy River	21 000				10 000			31 000
Fraser Island		155 000			3 000			158 000
Kolan River	39 000	1 000	6 000		245 000			291 000
Logan-Albert Rivers	7 000	27 000			370 000		7 000	411 000
Maroochy River	31 000	3 000		1 000	109 000		1 000	145 000
Mary River	273 000	7 000			652 000	1 000	9 000	942 000
Noosa River	47 000	72 000			43 000	23 000	1 000	186 000
Pine River	11 000	2 000	3 000		130 000			146 000
South Coast	5 000	8 000			113 000			126 000
Stradbroke Island		15 000			29 000			44 000
No data (slivers)		24 000			28 000	1 000		53 000
Total	928 000	401 000	30 000	2 000	4 726 000	32 000	24 000	6 143 000

Source: NFI database 1997

Notes: AWRC basins from 1:5,000,000 Australian Water Resource Commission basins coverage.
Rounded to nearest 1,000 ha.

1.4.2 Groundwater resources

The region's principal types of aquifers are: sand dune, alluvium, fractured rock, and porous sedimentary rock. In massive intrusive and extrusive igneous rock, water occurs within the joints of the rock. The degree of fracturing of the rock mass is highly variable, being a function of the geological history of the region Fracturing contributes to porosity. Porosity is also a function of weathering. Most weathering occurs along fracture planes, at shallow depths and in association with faults. Where groundwater occurs, higher yields will be associated with rock boundaries and major lineaments and faults.

The sand dunes and sand dune islands of South East Queensland have good supplies of groundwater. On North Stradbroke Island, in the south east corner of the region, good quality groundwater occurs as a lens with the watertable 60 metres above sea level at its highest point. This freshwater lens is maintained in equilibrium with the surrounding sea water (Australian Water Resources Council 1975).

1.5 AQUATIC ECOSYSTEMS

Streams, floodplains, wetlands and estuaries in South East Queensland support aquatic ecosystems with important biodiversity, fisheries, and nature conservation values. The Moreton Bay area has wetlands that have been listed under the *Ramsar Convention*.

The Queensland Government's Water Allocation and Management Planning (WAMP) process recognises the importance of maintaining the water needs of aquatic ecosystems (environmental flows). Under the process, a panel of environmental scientists will be appointed to identify the environmental flow requirements of each basin. Specific water allocation for the environment will then be determined by a regional community reference panel and the Department of Natural Resources (Department of Natural Resources 1997a).

It has been proposed that several of the State's river basins be evaluated under both the WAMP process and a similar process, the Water Management Planning (WMP) process. Few of South East Queensland's river basins have been identified for inclusion in these processes in the near future (Department of Natural Resources 1997a, 1997b).

It is expected that environmental flows in Queensland will largely be defined in terms of flow rates, duration and timing, and maximum levels of flow. It is also expected that the variable nature of streamflows in many parts of Queensland will be recognised when environmental flows are determined, and that flows will be monitored at critical points in each catchment. This will be achieved through the use of the State's stream gauging network (Department of Natural Resources 1997a).

2. RELATIONSHIP BETWEEN LAND USE AND CATCHMENT & WATER VALUES

2.1 AGRICULTURE/GRAZING

Agricultural expansion since European settlement has been associated with extensive clearing of forests and woodland and subsequent replacement of native grassland with exotic species. These land cover changes affect catchment hydrology:

- removing deep rooting vegetation, especially trees, and replacing it with crops and pastures decreases evapotranspiration losses and increases surface runoff and watertable recharge (Ruprecht & Schofield 1989);
- water storages, including farm dams, reduce streamflow particularly during low flow conditions (Ockenden & Kotwicki 1982; Cresswell 1991; Good 1992).
- there is an inverse relationship between water infiltration rates and grazing intensity: the heavier the grazing intensity the greater the soil compaction that occurs, which reduces water infiltration.
- in the case of croplands, the density of the groundcover, which varies seasonally or at least with the lifetime of the crop, is significant: bare or fallow ground produces the most runoff, closely grown crops result in least runoff (Ring & Fisher 1985).

In response to land degradation problems, often initiated by clearing for agricultural production and inappropriate management practices, farmers have been encouraged to construct contour banks, grassed waterways and farm dams to form integrated erosion control networks. These structures modify catchment surfaces, impede the movement of water within a catchment, and ultimately reduce streamflow. In one study, where the catchment had conservation treatments including perennial pasture, three-year crop rotations and extensive contour banking, a 24%-43% reduction in runoff was measured at different times in the study period (Baird & Richardson

1969). Diverting water for irrigation reduces downstream flow, a situation that is already leading to competition between users and can potentially lead to conflict between users.

Agricultural practices, including clearing, cropping, overgrazing, farm access tracks and stock access to streams, disturb the ground surface and 'mobilise' sediments. The proportion of sediments that is delivered to stream networks is a function of rainfall intensity and duration, slope, soil erodibility, soil particle size, continuity of the drainage network (the degree of connectivity between the erosion gully network and the fluvial system) and land cover. Sediment transport data (as turbidity or suspended sediment concentrations) are indicators of erosion within a catchment. Evidence suggests that agriculture is a regional factor in the degradation of water quality values and changes in streamflow within catchments (Ring & Fisher 1985, Neil & Fogarty 1991, Erskine 1992).

Even though the above Australian studies were not conducted in the South East Queensland region, there is no reason to presume that similar effects would not be observed in the region.

2.2 PLANTATIONS

2.2.1 Introduction

South East Queensland has a significant plantation forestry industry. According to National Forest Inventory data (1997), South East Queensland's plantations amount to about 14% of the national plantation estate. More than 90% of the region's plantations are State-owned; the Centre for International Economics (1997) estimates that 7% of the region's plantations are privately owned.

The region's plantation resource is dominated by two kinds of softwood: native hoop pine *(Araucaria cunninghamii)* and two exotic pine species (caribbean pine, *Pinus caribaea*, slash pine, *P. elliottii*, and a hybrid of the two), with an additional 3500 hectares of minor softwood species. A comparatively small area is currently growing hardwood species (National Forest Inventory 1997). See Table 2.2.1 for details.

References to the 'exotic pine' estate in South East Queensland usually mean the *Pinus (caribaea* and *elliottii* and hybrids) estate, which represents about 70% of all softwood plantations.

TABLE 2.2.1 SOUTH EAST QUEENSLAND'S PLANTATION ESTATE

Plantation type	species	common name	area
Softwood			147 370
exotic pine	Pinus caribaea	caribbean pine	34 540
	P. elliotti	slash pine	55 940
	P.caribaea/elliotti hybrid		11 570
	P. radiata	radiata pine	860
	minor species		2 060
native pine	Araucaria cunninghamii	hoop pine	41 930
	Araucaria bidwillii		420
	Agathis robusta		40
Hardwood	various species		1 120
TOTAL			148 500

Note - columns may not add up exactly due to rounding. Source: National Forest Inventory database (1998)

Hoop pine plantations have principally been established on ex-rainforest sites where the soils are usually deep and well drained. The terrain is often steep. The plantations of caribbean and slash pine and their hybrids have largely been established on the coastal lowlands where soils are often duplex; that is, where a shallow topsoil overlies a relatively impermeable subsoil.

The soil and topography of each plantation type have different hydrological properties. Ryan and Gilmour (1985) suggested that when the changes to evapotranspiration following clearfelling result in extra water infiltrating the soil, the coastal lowlands may develop 'perched' watertables, whereas the ex-rainforest soils and topography would tend to allow the flow of water into deep local watertables and thence into streamflow, by increasing the baseflow (groundwater discharge to streams). The effects of clearfelling will also include increased surface runoff. Depending on the degree and extent of soil disturbance, particularly compaction, this may initiate erosion, and hence may affect stream water quality and sedimentation (Ryan & Gilmour 1985).

The Department of Primary Industries–Forestry (DPI – Forestry) and the Department of Natural Resources (DNR) manage South East Queensland's publicly owned hoop pine and exotic pine plantation resource. The departments have responsibilities under the *Forestry Act 1959* and the Code of Practice for Plantations for Wood Production (DNR 1998a) (see Appendix 2 for an overview of the management of catchment and water values) to aim to protect catchment values, to protect the environment and water quality, and to have due regard for the conservation of the soil. A raft of measures are in place to conserve soil and protect water quality, including watercourse protection guidelines, plantation planning and location constraints, silvicultural systems aimed at limiting soil movement, classification of hill slopes according to soil erosion risk, devoting special attention to the proper drainage of the roading network, and providing soil cover, where necessary, by sowing grasses or cereals. The watercourse protection guidelines are in the department's silvicultural manuals for hoop pine and exotic pine (DPI – Forestry 1996, 1995a). The guidelines are reproduced at Appendix 3. The *Environmental Protection Act 1994* applies on all tenures including State Forest and is administered by the Department of the Environment. The Act requires the employment of all reasonable and practicable measures to prevent or minimise environmental harm, and provides for the application of penalties where breaches occur.

2.2.2 Hoop pine plantations

Much of South East Queensland's hoop pine plantation resource has been established in the upper reaches of the Brisbane and Mary River systems. Both river systems are important water resources for the population of South East Queensland. Therefore the catchment, habitat and water production values of the hoop pine plantation estate are significant (Costantini et al 1993b) and watercourse protection is a major management priority for DPI – Forestry and DNR. These departments have a watercourse protection system for hoop pine plantations. This system was reviewed in 1993 and research needs were identified. These needs included gathering quantitative information (because it was acknowledged that the current system was largely the result of experiential and observational evidence) (Costantini et al 1993b). As a part of attempts at continual improvement of the watercourse protection system, the potential of various indices to predict gully erosion was investigated (Costantini et al 1993a).

For the purposes of hoop pine management DPI – Forestry classifies watercourses as large, medium or small streams; major or minor gullies; or waterways. As a result of observations made after severe storms in March/April 1989, departmental researchers recommended that the existing riparian protection system be extended to exclude machinery from all streams and gullies, and to protect all watercourses to their uppermost reaches in the landscape (Costantini et al 1993b). The computer-based TOPOG terrain analysis and hydrologic modelling package was also investigated for the purposes of predicting the location of gully erosion resulting from storms. The TOPOG indices of ‘surface wetness’ and ‘stream power’ appeared to have potential for predicting gully erosion hazard (Costantini et al 1993a).

Research studies on soil loss in hoop pine plantations in the region have also included using the ‘erosion pin’ technique, as discussed by Costantini et al (1993c); and the development of a research methodology to provide information on the magnitude of soil loss from plantations on steep slopes (Costantini et al 1991). The methodology involved runoff plots, rainfall simulation, soil physics and modelling, and examined present practices and the relative soil conservation efficiencies of alternative management practices.

Results from the ‘erosion pin’ research indicate that soil losses from plots in hoop pine plantations can be extrapolated to a mean loss of 7.3 tonnes per hectare over a 50-year rotation, which is 25% less than the 10 tonnes per hectare per year associated with agricultural systems. However, both rates exceed the rate of soil formation and therefore represent significant net soil loss. Most of the soil loss in the study (85%) occurred in the first year after site treatment, when ground cover was negligible. These results emphasise the fact that the risk of erosion varies throughout the lifetime of a plantation, and that it is highest after harvest and before the new plantation is sufficiently established to provide adequate ground cover. Heavy rains during this period can result in severe soil loss.

Ryan and Gilmour (1985) reported that water yields increase after logging in hoop pine plantations. They estimated, for example, ‘that water yields at Imbil, in South East Queensland, will more than double, from 320 mm to 720 mm a year’, after the current hoop pine crop is harvested. However, there appears to have been little investigation of evapotranspiration processes in hoop pine plantations, or of any possible relationship between plantation crop age and water yields. If such a relationship exists (as it does in other forest types), it may have significance because, although only about 2% of the total catchment areas of the Brisbane and Mary Rivers are covered in hoop pine plantations, the plantations are located in the upper catchment (high rainfall) areas. The quality of runoff water from the plantations is currently being monitored, together with hillslope erosion. As yet results are unavailable, however, observations and grab samples suggest that the forestry department’s hillslope and watercourse protection mechanisms described by Costantini et al (1993, 1997a) are delivering high quality runoff water (Costantini pers. comm. 1997).

2.2.3 Exotic pine plantations

Management policy of exotic pine plantations in South East Queensland requires the sustainable production of wood and water while protecting stream, riparian, native forest and conservation values in accordance with legislation as defined by the *Queensland Forestry Act 1991*. According to Costantini et al (1997b), the most significant challenges to ecologically sustainable management of exotic pine plantations is the prevention of degradation of soil and water values. In order to protect these values, plantation areas are classified into three categories of management unit:

streams, road systems, and hillslopes. Management strategies vary for each unit to minimise sediment production and transport.

Hillslopes and stream banks are relatively stable when vegetation, including groundcover, is undisturbed (although soil moisture content and physical characteristics, including shear strength parameters, are important factors in slope and bank stability). Disturbance of the ground surface by machinery and harvesting operations increases the erosion risk by changing surface conditions. The time of greatest risk is the inter-rotation period, the time between harvesting one crop and regrowth of the next, when mechanical activity is greatest and vegetation cover is minimal (Costantini et al 1991).

The soils on which the region's exotic pine plantations are located, are generally coarse textured and nutrient deficient (Simpson & Grant 1991). Traditional site preparation practices, including removing harvest residue, windrow burning/clearing and broadscale burning, adversely affect soil structure, soil moisture availability and nutrient supply. Furthermore, these practices expose the surface soil to raindrop impact and surface runoff processes, thereby increasing the erosion hazard (Rose 1988; Costantini et al 1991).

Heavy machinery compacts soil, reducing porosity and permeability (Moore et al 1986), infiltration (Greacen & Sands 1980) and soil physical fertility. The direct hydrological effects of such changes include increased surface runoff (and consequently, sediment mobilisation and transport, or erosion) and consequent reduction in groundwater recharge. Compaction associated with forest operations mostly occurs during establishment, thinning and clearfelling. The severity of compaction and the size of the area affected increase as the levels of disturbance and soil moisture content increase.

A 1989 study at the exotic pine plantations at Toolara indicated that for selective thinning operations, the area severely affected by compaction increased by 36% when soil moisture was high. The study also found that in clearfelled areas 31% was severely compacted during harvesting (Costantini, 1995). As a result of this study and others investigating the effect of compaction on crop growth, Queensland DPI – Forestry introduced strict guidelines to control compaction, based on prescribing machine usage and maximum acceptable rutting depth (Costantini et al 1997b).

Studies in a number of small catchments in South East Queensland indicate that plantation establishment increases stream sedimentation in the first few years of the rotation (Cassells et al 1982). The data suggest that in the catchments studied, high sedimentation levels were related to wet years, although no data are available for these catchments on an 'event' basis (after individual storms or periods of heavy rain). However, it has been shown elsewhere that measured suspended sediment loads are storm-dominated, that is, high levels occur immediately after storms (Olive & Rieger 1987, Williams & Mackay 1988).

Studies in south-eastern Australia have shown that the coincidence of exotic pine plantation establishment and heavy rains can result in land degradation and reduced water quality (Prosser & Soufi 1997). While subsequent plantation growth will protect against the initiation of erosion, gullies incised during establishment will continue to develop. This hazard may be a consideration within the South East Queensland region where erodible soils occur (particularly texture contrast soils).

Studies in NSW have also demonstrated significant increases in sediment yield over 'natural' values by more than three orders of magnitude (Neil & Fogarty 1991); however, the method of estimation of this value and in particular, the definition of 'natural' is unclear. Estimates are based on clearfelling operations. In south-eastern Australia, studies of sediment deposits associated with plantations of various ages demonstrate greater sediment delivery rates from plantations established in the early 1970s than from those established in 1984 (Erskine 1992). These differences may be a function of changing management practices. In the 1970s few environmental protection practices were in place; by the 1980s, a number of protective prescriptions had been adopted, including filter strips and improved road construction and maintenance. However, the influence of climatic factors may also be contributory (ibid). The coincidence of heavy rains and the establishment of pine plantations is a significant factor in the initiation of erosion gullying, particularly on susceptible soils where effective hillslope and watercourse protection practices are not used (Costantini et al 1997b).

Within South East Queensland's publicly owned exotic pine plantations, the risk of erosion and therefore operational practices vary according to the type of system used to prepare the ground for planting. For continuous mounded systems (developed by Foster and Costantini 1991 a, b and c), DPI – Forestry have developed hydraulic and erosion models to predict optimal flow velocities along furrows, with variable recurrence intervals according to the rainfall intensity zone in which the plantation is located. Systems that have been constructed according to specifications demonstrate erosional stability (Costantini et al 1991). Erosion hazard prediction and erosion mitigation strategies for non-furrow based systems rely on the Universal Soil Loss Equation (Wischmeier & Smith 1978). A limit of soil loss at 300 tonnes per hectare per rotation has been adopted based on recommendations for forested areas in northern America (Dissmeyer & Foster 1980). However, in common with other applications of the equation, this approach cannot be applied reliably to Australian conditions and predictions have not been verified locally (Costantini, 1989). Furthermore, the equation's reliability is compromised by a number of inherent assumptions (Costantini et al 1997b).

Erosion mitigation strategies based on residue retention have been introduced progressively since the mid-1980s and will be in use across the entire publicly owned plantation estate in the South East Queensland region by the year 1999. These strategies complement existing strategies based on sowing cover crops immediately after clearfelling (Podberseek & Costantini 1994), 'spot' cultivation and strip cultivation along the contour. The increase in soil moisture and consequent deleterious effects on tree growth where minimum tillage is practiced has raised the question of tree breeding to select types that are tolerant of periodic saturation (Costantini et al 1997b).

2.2.4 Private plantations

There is little published or readily available information on the catchment and water values of South East Queensland's private exotic pine plantation estate. However, some information is available from studies undertaken in the Pumicestone Passage catchment.

The Pumicestone Passage is a narrow, shallow estuary that separates Bribie Island from the mainland. It is on the Register of the National Estate.

Extensive areas of the catchment are forested and a 1991 study found that forestry was the predominant land use (Queensland Department of Environment and Heritage 1993). The forested land includes areas of privately owned pine plantations that comprise approximately 35% of the total pine plantation area in the catchment. (Other land uses include urban, agriculture and horticulture, forestry in State forest). These industries and the urban populations, together with local aquaculture industries, represent potential sources of pollutants, sediments and nutrients that could adversely affect Pumicestone Passage waters (Queensland Department of Environment and Heritage 1993). One of the land cover changes and potential sources of sediment/pollutants that has been occurring since the early 1990s, is the logging of the private pine plantations.

Local strategies have been prepared to protect water quality and the ecological values of the Pumicestone Passage, its catchment and Bribie Island. Monitoring the water quality of estuarine streams draining the catchment is an important means of identifying potential threats to the natural values of the passage that result from catchment land use changes (Queensland Department of Environment and Heritage 1993). Because of the importance of the environmental values of the Pumicestone Passage, there have been two major catchment studies involving the monitoring of water quality in this area:

(i) a 1978-1980 study (Queensland Government Inter-Departmental Committee 1982), and

(ii) a 1991-1992 study (Queensland Department of Environment and Heritage 1993).

A third study involves a program to monitor the estuarine water quality of streams draining the private pine plantations surrounding Pumicestone Passage before and after logging activities. Reports on this monitoring have been prepared by WBM Oceanics on behalf of Queensland Commodity Exports (Queensland Department of Environment and Heritage 1993).

The 1993 Queensland Department of Environment and Heritage report raised theoretical concerns relating to logging activities. The report identified the possibility of acidic leachates from harvested forest areas entering groundwater, thereby reducing water quality, and recommends tighter controls on harvesting procedures, particularly in regard to silt management. The report also suggested that the passage be monitored for sediment and some of the catchment creeks be monitored for redox potential, total organic carbon and pH.

2.3 NATIVE FOREST MANAGEMENT

2.3.1 Introduction

State-managed native forest in the South East Queensland region consists of the following forest types (South East Queensland RFA information kit, 1997):

- remnants of sub-tropical and warm temperate rainforest, with a major occurrence in the McPherson Ranges and the Brisbane and Mary River Valleys;
- moist eucalypt forests, mainly restricted to rainforest fringes;
- dry eucalypt forest;

- cypress pine forest, occurring as pure stands or in mixture with spotted gum, ironbark and others.

DPI – Forestry and DNR manage all State forests in Queensland (see Appendix 2 for an overview of the management of catchment and water values). In contrast to the clearfelling operations carried out in State plantations, State native forests are harvested using selection logging. Typical levels of tree retention across the South East Queensland region are provided in Table 2.3.1. These data demonstrate the high level of tree retention in the selection logging process, and demonstrate the difference between DNR and DPI – Forestry's native forest logging operations in Queensland and those in other parts of Australia. For the purpose of harvesting in native forest, DPI – Forestry has developed a manual based upon the Australian Forestry Council's publication, *Forest Practices related to Wood Production in Native Forests: National Principles*. In the manual (DPI Forestry 1995b) some watercourses are classified as 'designated', meaning that buffer strips of vegetation must be retained and the stream must not be disturbed, during harvesting. The risk of soil erosion (and hence adverse effects on stream water quality) is a major reason for 'designating' watercourses. Soils have also been classified on the basis of their erodibility, using a combination of soil texture and colour properties, with secondary references to geology (see Appendix 4). Special attention is also paid to the siting and drainage of the roading network (DPI – Forestry 1995b). The Code of Environmental Practice for Native Forest Timber Production (DNR 1998b) contains schedules for planning, roading, temporary roads, snig ramps and tracks, watercourse protection, soil erodibility classification, silviculture, visitor values and landscape management. The code was implemented in April 1998 and refers extensively to the Harvesting, Marketing and Resource Management Manual (DPI Forestry 1995c), but since its implementation, supersedes this manual.

Harvesting operations are planned in advance of operations. Planning includes identification of areas in which harvesting is restricted, principally for protecting soil, water and stream habitat values (see Appendix 5).

TABLE 2.3.1 TYPICAL LEVELS OF TREE RETENTION IN SELECTION LOGGING

Size classes (cm DBH)	10-19.9		20-29.9		30-39.9		40-49.9		50-59.9		60-69.9	
logging status	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post
Dry forest (stems/ha)	128	128	54	47	29	26	19	14	12	7	7	4
Moist forest (stems/ha)	168	155	98	89	54	48	29	24	19	11	5	3
Wet forest (stems/ha)	247	230	108	100	56	54	34	28	27	21	11	6
Average (stems/ha)	181	171	87	79	46	43	27	22	19	13	8	4

Notes:
Source - extracted from DPI – Forestry's permanent plot inventory database - i.e. from DPI Forestry 'detailed yield plots'.
Sample of plots across South East Queensland for all living trees (commercial and non-commercial)

2.3.2 Roading and harvesting

In Victoria's ash-type forests, a positive relationship between the frequency of road use and the production of *coarse* sediment and total sediment has been determined (Haydon et al 1991).

Sediment production from roads may be affected by forest management systems. For example, according to O'Shaughnessy and Jayasuriya (1987), in clearfelling systems in ash forests, much of the road network can be closed and revegetated until the next rotation harvest time, but thinning and selection logging systems might require more regular access and hence the need to maintain the road network.

According to DPI – Forestry's harvesting guidelines for native hardwoods (1995b):

- Stream crossings are recognised as the largest potential source of stream sediment. Pre-harvest planning must ensure that the number of road crossings of major water courses is minimised.
- Sidecutting for road construction should be kept to a minimum, and should generally not be located on slopes greater than 30 degrees. Where there is potential for mass soil movement, sidecuts may be required to be battered and spill stabilised with a cover crop.
- Snigging should be directed away from watercourses to ramps located on ridges.
- Log ramps are to be located on ridges wherever possible and where practicable on slopes not exceeding 6 degrees.
- Snigging operations are to cease when soil becomes saturated and/or free surface water commences to run in watertables or on log dumps.
- All harvesting equipment introduced after 1st of January 1992 should be capable of raising the front end of the load during snigging, in order to prevent the ploughing effect on the soil by the front end of the log. However, due to the log size or steepness of terrain, raising logs during snigging is not always possible or safe to carry out.

2.3.3 Recreation and tourism

Forested catchments including State forests and national parks are popular recreational destinations in South East Queensland. Moreton Island and Fraser Island are declared recreation areas under the *Recreation Areas Management Act 1988.* This status allows recreational activities to be coordinated across a number of land tenures, including national park and State forest (Australian Bureau of Statistics 1997). Potentially, these activities can adversely affect water quality. Bacterial contamination and particulate waste disposal from tourist camping sites, and increased turbidity in response to sediment mobilisation from disturbed tracks and roads are hazards associated with tourism and recreation. The positive relationship between the frequency of road use and the production of sediment mentioned above may be exacerbated by the recreational activities in forests, particularly the use of 4WD vehicles.

To various degrees, recreational activities also occur in Brisbane's water supply catchments. Three of Brisbane's oldest reservoirs, Enoggera, Gold Creek and Lake Manchester, all have largely forested catchments. Recreational use of the water storages themselves is prohibited; however, the catchments may be used by hikers or for nature study (where permits have been issued) and forestry operations are generally allowable (Australian Water Resources Council 1985).The prescriptions for the Enoggera Dam catchment do not permit grazing or apiculture and access to forest areas is restricted. These restrictions limit general vehicle use and human presence in the area. However, there are no special logging restrictions for this catchment. The usual practices are applied (Neil Gooly, DPI – Forestry, pers. comm. 1997). These catchments contribute about 10.5% to Brisbane's water supply and any adverse effects of land use on the quality of the reservoir water are likely to be minimal.

By contrast, there are fewer restrictions on recreation in the catchments of Brisbane's newer reservoirs (Somerset Dam, Wivenhoe Dam and North Pine Dam). These dams were built specifically for multiple purposes, including flood control and water supply (Australian Water Resources Council 1985).

2.3.4 Water use in forested catchments

The forested catchments of South East Queensland have multiple uses, all of which affect the value of the water resource to a greater or lesser degree. Changes in land use over time will affect hydrological responses. When water quantity and quality are measurably reduced by such activities, the acceptable limits of those changes will depend partly on the value placed upon the water and aquatic environments. The value placed on the water will be determined in part by how it is to be used.

Land use, surface condition of the land and degree of disturbance are determined by land tenure, which in turn governs access and management strategies. As discussed earlier, agricultural activities can significantly and adversely affect water quality and quantity. In addition, forest hydrological research has indicated that forest operations may adversely affect the water resource, with implications for public land managers. The amount of research on native forest hydrology in the South East Queensland area is limited. However, the following section reviews relevant research in other forests, discusses the issues of water quality and quantity and examines management strategies which relate to those issues.

In moist sclerophyll forests in New South Wales correlations have been demonstrated between clearfelling or wildfire and increased baseflow (groundwater discharge to streams) and peak flow (highest stream flow) (Mackay & Cornish 1982). In these forests, runoff returned to levels prevailing before the harvest within eight years total (Mackay, 1989). Harper & Lacey 1997 have stated that in dry sclerophyll forests residual effects were still apparent after 10 years in the most intensely disturbed catchments. However the persistence of these effects is not known. In high rainfall mixed species forests in north-eastern New South Wales, water yields increased in the first year after clearfelling, then began to decrease from this high point about two years after logging, as a result of abundant regeneration (Cornish 1993).

Further decline in water yield in the following four years, to a value significantly lower than pre-treatment levels, was related to the mean stocking rate of the eucalypt regeneration (that is, the regeneration was denser than the forest it replaced). However, in a catchment where the effective area of vegetation reduction was less than 20% of the total catchment area, no initial increase of catchment yield occurred. It is unknown whether yield reductions in response to regrowth occurred during subsequent years.

Based on a broadscale review of world-wide data, Bosch and Hewlett (1982) estimated that the relationship between reducing forest cover and the rate of increase in catchment yield was 40 mm per year increased yield for every 10% reduction in forest cover. Estimates for ash-type forests put the relationship at 33 mm per year per 10% cover reduction.

Research in mixed species forest in New South Wales has not provided consistent results concerning the rate or extent of the changes in water yields from forested lands following clearfelling or fire, in comparison with pre-treatment levels. Harper and Lacey (1997) suggest that although all runoff parameters increase in response to logging and wildfire, there is no evidence to suggest that total yield is reduced to below pre-treatment levels. This finding is in contrast to results derived by Wronski and associates (1993) for mixed species forest, and by O'Shaughnessy and Jayasuriya (1987), for ash-type forests, where research results indicated a reduction in water yield to below pre-harvest or fire levels during the regrowth period. These varied results emphasise the need for more research.

South East Queensland's publicly owned native forests are harvested using selection logging (that is, clearfelling techniques are not used) and there are numerous differences between Victoria's ash-forest types and those in South East Queensland; in terms of forest vegetation, climate, geology and topography. Therefore, forest hydrology research in south-eastern Australia may hold little relevance for the South East Queensland situation. Certainly, in catchments with multiple uses and a small percentage of forest cover, the effects of selective logging will probably be minor, and at a catchment scale may be 'buffered out' by the effects of other land uses and management changes.

It is recognised that plantations and native forest are usually found in the headwaters of water supply catchments in South East Queensland, and that clearfelling and replanting operations in the plantations are likely to affect water yields (Ryan & Gilmour 1985). These effects, however, have been assessed at a local rather than catchment scale. The example mentioned earlier, of water yields at Imbil more than doubling following clearfelling of the hoop pine crop (Ryan & Gilmour 1985) discussed 'increased water yield' in the localised context of increased erosion, local water quality and nutrient depletion issues, rather than as an issue affecting stream flow and water supplies in the whole catchment. It should be noted that only about 1000 hectares are clearfelled each year and this area is replanted. In a combined catchment of some 23 000 square kilometres, the increase in runoff attributable to the plantation harvesting will not be discernible at a catchment scale.

Moist eucalypt forests in South East Queensland, such as those dominated by the tall ('ash-like') *E. grandis*, are mainly restricted to rainforest fringes, and can be found, for example, in the Conondale forests. If a wildfire resulted in extensive areas of dense regeneration of even-aged, rapidly growing *E. grandis* seedlings, it would be interesting to know whether a hydrological response typical of ash-type forests would occur. However, the probability of such a fire is low, given the distribution of wet sclerophyll forests and the rarity of fires with sufficient intensity to kill mature forest (which would result in a flush of regrowth).

Government forest initiatives, such as Plantations for Australia: the 2020 Vision, the Wood and Paper Industry Strategy, the National Farm Forestry Program, the Queensland Government's Private Forestry Plantation Initiative, and other programs and policies are encouraging the development of more plantations on cleared, privately owned land, including land in South East Queensland.

Changes in land use from cleared/agricultural to plantation will affect catchment hydrology, the magnitude of which will be a function of climate and the proportion of catchment involved. While reduced runoff may raise potential conflicts between users downstream (including the environment), the lowering of watertables may help ameliorate dryland salinity. This effect may be important in the South East Queensland region, where some agricultural land is affected by dryland salinity (Hughes 1984) and may be ameliorated by plantation development. However, there appears to be little information or research data available on the expected hydrological effects (stream flow, water quality and water supplies) of new plantations on cleared land in South East Queensland.

3. RESEARCH AND DEVELOPMENT NEEDS

3.1 WATER QUALITY AND SOIL EROSION ISSUES

DPI – Forestry has a long history of continuous improvement in management that is based on a commitment to research and development and has as a central aim, the improvement of environmental management. The department's approach has been to identify best practices, develop these to suit Queensland forests and use an adaptive learning model to improve performance (Costantini & Gilmour 1993). Generally, ongoing change occurs prior to comprehensive studies being published. Table 3.1 shows the department's current research projects relating to hydrological processes and responses.

TABLE 3.1 DPI – FORESTRY'S CURRENT HYDROLOGICAL RESEARCH STUDIES

LOCATION/ Study name	Year begun	Forest Type	Issues	METHOD/Objectives
TOOLARA Pinus plantation hydrology: groundwater study	1987	Exotic pine plantation	Groundwater, baseflow effects	PAIRED CATCHMENT STUDY 1. To investigate the impact of forest management on the groundwater of the coastal lowlands 2. To develop a model for predicting the impact of forest management on groundwater levels in the coastal lowlands.
TOOLARA Pinus plantation hydrology: sustainability study	1992	Exotic pine plantation	Water quality and quantity	NESTED CATCHMENT STUDY 1. To examine the impact of plantation management on water quality and quantity production; 2. To monitor catchment and hillslope soil loss following clearfelling and reforestation; 3. To develop an understanding of hydrologic processes operating in the coastal lowlands so that extension of findings into operational practice can be achieved.
IMBIL Hoop pine establishment: sustainability of hoop pine plantation management	1990	Hoop pine plantation	Hillslope processes	INDIVIDUAL RUN-OFF TROUGHS 1. To provide quantitative information on the sustainability of hoop pine plantation management; 2. To produce a planning model that will be able to predict soil loss under different management regimes; 3. To define operational limits for various management practices.
IMBIL water quality	1997	Hoop pine plantation	Risk assessment of stream water contamination by herbicide	NESTED CATCHMENT STUDY 1. To investigate the pattern, duration and range of atrazine concentrations in surface waters resulting from routine spray applications of atrazine; 2. Assess the risk of atrazine contamination occurring in surface waters at levels in excess of NH&MRC guidelines and levels recognised to cause adverse environmental effects.
JIMNA Ecologically sustainable native forest management - paired catchment study	1995	Native Forests	Water quality and quantity	PAIRED CATCHMENT STUDY To assess the impacts of selection logging on biological, hydrological, and edaphic parameters and processes in a tall mixed eucalypt forest. 1. Monitoring water quality and quantity using paired, instrumented catchments. 2. After a period of calibration (five years), introduce logging to one catchment and monitor changes in hydrologic parameters and compare logged and unlogged catchments. 3. There will be a number of ancillary projects using the paired catchment site, some by external agencies (eg. universities)

Sources: T.Costantini, K. Bubb (DPI-F) pers. comm. 1997; Australian Rural Research in Progress (ARRIP) database (1997)

Table 3.1 shows that paired catchment studies are now underway in native forests and plantations in South East Queensland. The Toolara study started more than 10 years ago. Unfortunately most of the other studies listed are too new to have yielded results on water quality and quantity yet. 'Grab samples' of water quality data may be available from some studies, as suggested in section

2.2.2. The Queensland Forestry Research Institute (QFRI) has provided a sample of pre-harvest water quality in streams in Toolara *Pinus* plantation and Jimna native forest (see Table 3.2). However, no post-harvest data are available. The use of pre-harvest data alone limits any assessment of the water quality effects of South East Queensland's harvesting operations. The current lack of availability of reliable forest hydrological data from South East Queensland can be explained as being the result of a number of factors (K. Bubb, DPI F pers. comm. 1998):

- Historically, DPI – Forestry's hydrological research has received less funding than studies in south-eastern Australia. Therefore there have not been as many paired catchment studies set up in South East Queensland as there has been in the southern States.
- There has been a prolonged drought in South East Queensland in recent years. The drought has affected the variability of stream flows and the reliability of the data collected.
- The weirs constructed in South East Queensland for water monitoring have been fairly shallow and the flows during big storms have not been properly monitored.
- A calibration period of baseline monitoring is required before logging treatments are introduced to paired catchment studies. In the case of the Jimna study, the calibration period is expected to be five years. No logging has commenced yet at Jimna, so no post-logging data are available from this study.

TABLE 3.2 WATER QUALITY (PRE-HARVEST) IN STREAMS AT TOOLARA AND JIMNA

Study Location	Year begun	Forest type	Analyte	Range	Mean
TOOLARA	1987	Exotic pine plantation	Total Nitrogen (mg/l)	0.5 to 1.5	1.1
			Total Phosphorous (mg/l)	<detection limit	-
			Total Potassium (mg/l)	0.5 to 2.5	1.5
			Suspended solids (mg/l)	10 to 90	25
			pH	5.5 to 6.5	5.8
			Conductivity (µS/cm)	130 to 270	175
JIMNA	1995	Native forest	Total Nitrogen (mg/l)	0.2 to 0.7	0.5
			Ammonia (mg/l)	<detection limit	-
			Nitrate (mg/l)	<detection limit	-
			Total Phosphorous (mg/l)	<detection limit	-
			Orthophosphate (mg/l)	<detection limit	-
			Total Potassium (mg/l)	0.5 to 2.5	1.2
			Conductivity (µS/cm)	40 to 160	110

Source: Queensland Forestry Research Institute

< less than

Costantini et al (1997b) suggested that, because many of DPI – Forestry's soil and water protection practices are not based on comprehensive research results, there is an important need to quantify outcomes to assess whether management objectives are being achieved. They further suggested that there is a need to continue to develop management systems that ensure consistent operational quality, and that this will require the identification of key indicators of quality and performance, and the development of a program for monitoring and reporting.

3.2 WATER YIELD ISSUES

The Department of Natural Resources maintains a large network of stream gauging stations throughout South East Queensland. Data are managed through the 'Hydsys' system. In native forest areas, the gauging stations tend to be the responsibility of DPI – Forestry. Map 1 shows the stream gauging and water quality sites in the forested Conondale Ranges. The various managing authorities for these stations are also shown. DPI – Forestry is also responsible for the gauging stations on plantation land. However, logging histories are not on the centralised digital database for plantations maintained by DPI – Forestry; and hard-copy records of plantation logging histories are also not stored centrally (Malcolm Taylor, DPI – F, pers. comm. 1998). Therefore it was considered too difficult, within the time constraints of this project, to collate plantation logging records to link water quality and quantity data, in order to identify any effects. In terms of native forest data, the Department of Natural Resources maintains the logging histories of native forest logging in its digital databases, but the stream gauging stations in native forest tend to be maintained by DPI – Forestry for research purposes (J. Burgess pers. comm. 1998). Few, if any of the data from these research gauging stations have been published. Where data has been gathered it is often still in a raw and uninterpreted format (K. Bubb, DPI-F pers. comm. 1998), so the usefulness of this data for analysis by a third party for the purposes of this project was considered questionable, especially given other information concerning the reliability of this data (see dot points near end of section 3.1).

Accurate information about the water production values of all land uses would seem to be important, especially given that water supplies in South East Queensland will be under increasing pressure next century as the population of the region continues to grow, and there is further agricultural, industrial, urban development, and likely further plantation development.

Government reports rarely consider the water requirements of the forestry sector. For example, the State Water Conservation Strategy (Department of Natural Resources 1996), and the Water Infrastructure Taskforce Report (1997) frequently refer to agriculture as a user of water, but make no mention of forestry, despite the fact that trees generally transpire and intercept much more water than pasture and crops. Also, neither report considers the potential of plantation development on cleared agricultural land to influence water supplies and water infrastructure development in South East Queensland.

There is no evidence to suggest that the effects on water yields of current clearing practices; reafforestation practices; harvesting practices; wildfire; or enhancing the productivity of the native forest estate have been quantified in South East Queensland. In addition to the research in progress (described in Table 3.1), research aimed at answering the following questions would also be desirable:

- What are the implications to catchment and water values of the use and management of private plantations and private native forests in South East Queensland?

- How will water yields be affected if attempts are made to enhance the productivity of South East Queensland's native forest estate?

- How will the continuous improvement in softwood plantation productivity through genetics, nutrition or other management means affect water yields?

- Will the expansion of hardwood and softwood plantations in South East Queensland affect water yields?

- How do the evapotranspiration rates of plantations of softwood species, rainforest timber species, eucalypt species, etc. in South East Queensland differ?

- What will be the effects on dryland salinity-affected farms in South East Queensland by farm forestry plantings or regional plantation development in the catchments covering these areas?

In terms of future research and development in the hydrology of farm forestry and new plantations in South East Queensland, it would also be wise to consider the recommendations made in Stirzaker et al. (1996), where three equal priority research areas were identified:

- Develop a 'catchment classification system' based on knowledge of topography, geology, salt store, climate and vegetation at the regional scale. The classification system would help identify the catchments at most risk of land and water degradation, requiring urgent changes in land use. It would provide a framework for asking the right questions, and for directing data collection in more detailed on-site investigations.

- Establish guidelines for designing agroforestry systems to balance catchment health with tree productivity and agricultural productivity. Once a catchment has been identified as needing reafforestation, the guidelines would assist land managers to work out the area of land which must be planted, the location of plantings and suitable agroforestry designs.

- Determine the productivity and sustainability of plantations in regions with shallow watertables. Key issues are the potential build up of salt in the tree root zone, the role of irrigation with partially saline water, and the export of salt from these plantations.

4. CONCLUSIONS

From the assessment of hydrology, catchment and water values in South East Queensland, a number of conclusions can be drawn:

- South East Queensland is a rapidly growing and developing part of Australia with a diverse range of land uses.
- The region's water resources will be under increasing pressure to meet the needs of a wide range of users, and the environment.
- Forests are recognised as producing good quality water compared to other uses of land in the region's catchments.
- In terms of water quality, there is currently insufficient research available to gauge the effects of current forestry activities and practices.
- Government policy documents rarely consider the water requirements of the forestry sector.
- Few data are available on forest water yields and quality in South East Queensland, although paired catchment studies are now underway in both exotic pine plantations and native forest. Most of these studies are too recently established to have yielded results on water quality and quantity issues yet.
- In terms of water yield and town water supplies, forests and forestry activities are likely to be less important in South East Queensland than in many other regions of Australia because only a small proportion of the region's town water supplies are derived from completely forested catchments.
- Research in the publicly owned estate in South East Queensland has been focused on improving the operational systems of forest or plantation management in order to reduce soil erosion and improve local water quality. The development of operational systems for these aspects of management has largely been driven by observational and experiential evidence. This focus has been acknowledged in recent research reports and recommendations have been made to improve soil and water quality management systems by continuing this adaptive learning framework and supporting current management with overt demonstrations (monitoring systems) of sustainability, including the development of key indicators to be used as the basis of the monitoring process.

5. RECOMMENDATIONS

Several priorities for research and development in the region have been identified:

- Publication of data from the Department of Primary Industries – Forestry's current hydrological studies;

- Develop a quantitative basis for the Department of Primary Industries – Forestry's soil and water protection practices, and improve these practices based on results obtained from quantitative research;

- Develop scientifically-based soil and water monitoring systems using indicators that are nationally compatible and accreditable. Refine existing operational management systems to include the identification of key indicators and the development of a program of monitoring and reporting against these indicators. The current process of developing criteria and indicators under the ecologically sustainable forest management process, as a part of the comprehensive regional assessments leading to regional forest agreements, and under the Montreal Process, are relevant to the development of regional indicators, and should be taken into account.

- Investigate the water yield/water quality effects of current forest and plantation management and consider the effects that the establishment of new plantations on cleared agricultural land may have. Findings of significant change should be assessed for water supply policy implications.

APPENDICES

APPENDIX 1. SURFACE WATER RESOURCES OF SOUTH EAST QUEENSLAND, AND DRAINAGE CHARACTERISTICS OF AWRC BASINS

TABLE 1.4.2 SURFACE WATER RESOURCES WITHIN THE SOUTH EAST QUEENSLAND RFA REGION

Source	AWRC Basin	Storage Cap. (ML)	Owner	Nearest city or town	Purpose
Burnett River	136				
• Cania Dam		89 000	DNR	Monto	Irrig., Urban
• Claude Wharton Weir		12 580	DNR	Gayndah	Irrig., Urban
• Gordonbrook Dam		6 500	Kingaroy Shire	Kingaroy	Urban
• Bjelke-Petersen Dam		125 000	DNR	Murgon	Irrig., Urban
• Joe Sippel Weir		730	DNR	Murgon	Irrig., Urban
• Murgon Weir		500	DNR	Murgon	Irrig., Urban
• Silverleaf Weir		630	DNR	Murgon	Irrig., Urban
• Ben Anderson Barrage		27 600	DNR	Bundaberg	Irrig., Urban
Kolan River	135				
• Fred Haigh Dam		586 000	DNR	Gin Gin	Irrig., Urban
• Bucca Weir		9 780	DNR	Gin Gin	Irrig., Urban
• Kolan Barrage		4 000	DNR	Gin Gin	Irrig., Urban
Burrum River	137				
• Lenthall's Dam		15 500	Hervey Bay CC	Hervey Bay	Urban
• Burrum No. 1 Weir		1 400	Hervey Bay CC	Hervey Bay	Urban
• Burrum No. 2 Weir		1 590	Hervey Bay CC	Hervey Bay	Urban
• Cassava Dam		3 690	Hervey Bay CC	Hervey Bay	Urban
Mary River	138				
• Borumba Dam		33 400	DNR	Gympie	Irrig., Urban
• Imbil Weir		50	DNR	Gympie	Irrig., Urban
• Mary Barrage		11 700	DNR	Maryborough	Irrig., Urban
• Tinana Barrage		4 750	DNR	Maryborough	Irrig., Urban
• Teddington Weir		4 000	DNR	Maryborough	Irrig., Urban
• Cedar Pocket Dam		730	DNR	Gympie	Irrigation
• Six Mile Creek Dam		9 280	Noosa Shire	Noosa	Urban
• Baroon Pocket Dam		61 000	Caloundra/ Maroochy SWB	Maleny	Urban, Recreation
Maroochy River	141				
• Wappa Dam		4 600	Maroochy Shire	Maroochydore	Urban
• Cooloolabin Dam		13 600	Maroochy Shire	Maroochydore	Urban
• Poona Dam		680	Maroochy Shire	Maroochydore	Urban
• Intake Weir		80	Maroochy Shire	Maroochydore	Urban
• Ewen Maddock Dam		16 700	Caloundra Shire	Caloundra	Urban
• Mooloolah Diversion Weir		1 360	Caloundra Shire	Caloundra	Urban

TABLE 1.4.2 CONTINUED

Source	AWRC Basin	Storage Cap. (ML)	Owner	Nearest city or town	Purpose
Pine River	142				
• North Pine Dam		202 000	SEQWB	Petrie	Urban, Recreation, Flood control
• Lake Kurwongbah		15 400	Pine Rivers Shire	Petrie	Urban, Recreation
Brisbane River	143				
• Somerset Dam		369 000	SEQWB	Kilcoy	Urban, Recreation, Flood control
• Wivenhoe Dam		1 150 000	SEQWB	Ferndale	Urban, Recreation, Flood control
• Splityard Creek Dam		28 600	AUSTA Electric	Ferndale	Hydro-electricity
• Mount Crosby Weir		2 600	Brisbane CC	Ipswich	Urban
• Lake Manchester		25 700	Brisbane CC	Ipswich	Urban, Rec.
• Enoggera Reservoir		4 500	Brisbane CC	Brisbane	Urban, Rec.
• Gold Creek Reservoir		1 600	Brisbane CC	Brisbane	Urban, Rec.
• Moogerah Dam		92 500	DNR	Boonah	Irrig., Urban
• Aratula Weir		50	DNR	Boonah	Irrig., Urban
• Churchbank Weir		180	DNR	Boonah	Irrig., Urban
• Warrill Creek Weir		unknown	DNR	Boonah	Irrig., Urban
• Atkinson Dam		31 300	DNR	Lowood	Irrigation
• Lake Clarendon Dam		25 000	DNR	Gatton	Irrigation
• Clarendon Weir		230	DNR	Gatton	Irrigation
• Bill Gunn Dam		7 500	DNR	Laidley	Irrigation
• Cressbrook Creek Dam		81 800	Toowoomba CC	Toowoomba	Urban
Logan-Albert Rivers	145				
• Maroon Dam		31 800	DNR	Rathdowney	Irrig., Urban, Industry
• Bromelton Weir		410	DNR	Beaudesert	Irrig., Urban
• Leslie Harrison Dam		24 800	Redlands Shire	Capalaba	Urban
South Coast	146				
• Hinze Dam		165 000	Gold Coast CC	Gold Coast	Urban
• Little Nerang Dam		8 400	Gold Coast CC	Gold Coast	Urban
Condamine-Culgoa Rivers	422				
• Cooby Creek Dam		23 100	Toowoomba CC	Toowoomba	Urban
• Perseverance Dam		30 900	Toowoomba CC	Toowoomba	Urban
Boyne River	133				
• Awoonga High Dam		270 000	GAWB	Gladstone	Industry Urban

Source: Water Infrastructure Task Force (1997)

TABLE 1.4.1 ESTIMATES OF THE AREA AND TOTAL ANNUAL RUNOFF OF EACH OF THE AWRC BASINS IN THE SOUTH EAST QUEENSLAND REGION.

Basin	AWRC No.	Drainage area km^2	Percent gauged	Estimated total annual runoff ('000 ML)
Boyne River	133	2540	88	410
Baffle Creek	134	3860	37	790
Kolan River	135	2980	80	680
Burrum River	137	3340	56	210
Mary River	138	9595	75	2280
Fraser Island	139	1685	0	720
Noosa River	140	1915	3	1000
Maroochy River	141	1410	11	740
Pine River	142	1555	45	570
Brisbane River	143	13560	88	1320
Stradbroke Island	144	505	0	190
Logan-Albert Rivers	145	4195	75	840
South Coast	146	1295	34	1050
Calliope River	132	2255	60	310
Fitzroy River	130	142645	96	5220
Burnett River	136	33150	99	1640
Condamine-Culgoa Rivers.	422	150220	100	1350

Source: Brown (1983)

APPENDIX 2. MANAGEMENT OF CATCHMENT AND WATER VALUES

Commonwealth policies and initiatives

Ecologically sustainable forest management

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

1. Commitment and policy framework

2. Planning

3. Implementation

4. Forest Information and monitoring

5. Review and improvement

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

General

Under the Australian constitution, the main responsibility for water resource planning and management lies with the State and Territory Governments. The Commonwealth Government has a complementary role in natural resource management. This relationship is best demonstrated in the Council of Australian Governments (COAG) Water Reform Framework (below). The InterGovernmental Agreement on the Environment and the National Forest Policy Statement are further examples of agreed frameworks for national approaches, having relevance to the environmental aspects of water resources. For example ‘Water Supply and Catchment Management’ have been jointly identified in the National Forest Policy Statement as one of the eleven broad national goals, to be pursued within a regional planning framework, in order to achieve the shared vision for Australia’s forests, agreed to by the Commonwealth, State and Territory Governments in the National Forest Policy Statement. The management of the Murray-Darling Basin is also an issue of importance to several States, as well as being a national interest issue. Thus, the Murray-Darling Basin Ministerial Council has representation from the Commonwealth and the States. Murray-Darling Basin issues are probably only of minor importance in the South East Queensland RFA region because the only Murray-Darling Basin catchment in the region is the Upper Condamine catchment. It also needs to be realised that Australia, as a nation, is a signatory to various international conventions. Some, such as the *Convention on Wetlands of International Importance (Ramsar Convention)* have direct relevance to South East Queensland, because Moreton Bay has important wetlands which have been listed under the *Ramsar Convention*.

COAG water reform framework

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

The key elements of the framework are:

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

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

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

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

National Water Quality Management Strategy (NWQMS)

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

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

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

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

National River Health Program (NRHP)

The objective of the NRHP is to improve the management of Australia's river systems through improved information bases on the state of rivers (Managing Australia's Inland Waters 1996). The NRHP was primarily established to implement the Monitoring River Health Initiative that aims to develop a national approach to river health monitoring. Another major component of the NRHP is developing means of assessing the water requirements that are necessary to maintain a healthy functioning river ecosystem (NRHP Leaflet 1993).

National Rivercare Initiative

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

State policies, legislation and initiatives

State Legislation

The following Queensland legislation has relevance to the management of catchment and water values in South East Queensland:

- *Forestry Act 1959-1984*
  - The Department of Primary Industries is obligated under the *Forestry Act 1959-1984* to protect catchment values, to protect the environment and water quality, and to have due regard to the conservation of the soil. To take account of these responsibilities watercourse protection guidelines have been developed for native State Forests and for both hoop pine and exotic pine plantations. In addition to water course protection, hill slopes are classed according to soil erosion risk and special attention is given to the proper drainage of the roading network etc.
- *Environmental Protection Act 1994*
  - The Act applies on all tenures including State Forest and is administered by the Department of the Environment. The Act requires the employment of all reasonable and practicable measures to prevent or minimise environmental harm, and provides for the application of penalties where breaches occur. The Act covers a whole suite of environmental management measures previously covered by the Clean Waters, State Environment and Litter Acts, and others. In Queensland, both the Department of the Environment and the Department of Natural Resources undertake water quality monitoring. The Department of the Environment monitors estuarine and coastal waters and the Department of Natural Resources monitors fresh water.
  - Two recent developments in forestry practice in Queensland are the Code of Practice for Plantations for Wood Production (DNR 1998a) and the Code of Environmental Practice for Native Forest Timber Production (DNR 1998b). The Code of Environmental Practice for Native Forest Timber Production contains schedules for planning, roading, temporary roads, snig ramps and tracks, watercourse protection, soil erodibility classification, silviculture, visitor values and landscape management. The code was implemented in April 1998 and refers extensively to the Harvesting, Marketing and Resource Management Manual (DPI Forestry 1995c), but since its implementation, supersedes this manual (J. Burgess DNR, pers. comm. 1998).
- *Environment Protection (Water) Policy 1997*
  - developed under the *Environmental Protection Act 1994*. Its approach is based on the National Water Quality Management Strategy (NWQMS). According to (Department of Natural Resources 1996) it will impact on Local Government and DNR by requiring the development and implementation of specific programs to:
    - manage sewage flows;

    - improve the quality of urban stormwater;
    - promote water use efficiency;
    - provide environmental water requirements;
    - protect groundwater

- *Nature Conservation Act 1992*
  - The *Nature Conservation Act 1992* provides for the declaration and management of protected areas for the conservation of the natural environment and species. Allocations of water, forest and fisheries resources must account for environmental and nature conservation standards, policies and plans under the *Nature Conservation Act 1992* (Department of Primary Industries 1994). The *Nature Conservation Regulation Act 1994* created 11 classes of protected area, including national parks and wilderness areas (Australian Bureau of Statistics 1997). Another issue which may be of relevance to the management of certain streams and catchments in Queensland is that the *Nature Conservation (Wildlife) Regulation Act 1994* lists four frog and three fish species as endangered, and four frog and two fish species as vulnerable (Australian Bureau of Statistics 1997).
- *Recreation Areas Management Act 1988*
  - Moreton Island and Fraser Island are declared recreation areas under the *Recreation Areas Management Act 1988.* This status allows recreational activities to be coordinated across a number of land tenures, including national park and State forest (Australian Bureau of Statistics 1997).
- *Coastal Protection and Management Act 1995*
  - Allocations of water, forest and fisheries resources must account for environmental and nature conservation standards, policies and plans under the *Coastal Protection and Management Act 1995* (Department of Primary Industries 1994).
- *State Development and Public Works Organisation Act*
  - Under the *State Development and Public Works Organisation Act* impact studies for all new major water infrastructure development projects are required. Both environmental and social impacts (European and Aboriginal) are assessed. An Environmental Management Plan is then produced, in the case where the impacts of the development proposal have been deemed to be acceptable (Water Infrastructure Taskforce 1997).

Other relevant legislation includes:

- *Water Resources Act 1989*

- provides for the establishment of Drainage Boards

- *River Improvement Trust Act 1940*
  - provides for the establishment of River Improvement Trusts
- *Local Government (Planning and Environment) Act 1990*
  - provides for land use planning and development control

- *Land Act 1962*
  - provides for lease conditions, clearing approvals and tree management plans.
- *Irrigation Act 1922-1977*
- *Water Act 1926-1979*
- *Soil Conservation Act 1986*
- *Soil Survey Act 1929*
- *Fisheries Act 1976*
- *City of Brisbane (Flood Mitigation Works Approval) Act 1952*
- *Brisbane Forest Park Act 1977*
- *Mineral Resources Act 1989*

State Policies, Programs and Initiatives:

Integrated Catchment Management (ICM)

ICM is a community-based approach to natural resource management which focuses on the development of strategies to achieve integrated management of land, water, forest, fisheries and related biological resources within a river catchment (Department of Primary Industries 1994). An Integrated Catchment Management Strategy was prepared by the Queensland Government in 1991 (Department of Primary Industries 1991) to provided for strategic planning through catchment coordinating committees which prepare catchment management strategies. The geographic basis for this planning may be at the catchment, sub-catchment, district, shire or sub-region levels.

Water Management Planning (WMP) and Water Allocation and Management Planning (WAMP)

The Queensland Government is currently introducing two planning processes that will result in the development of a management plan for each river basin, including groundwater basins. These planning processes are the Water Management Planning (WMP) process and, the more comprehensive, Water Allocation and Management Planning (WAMP) process. These processes will involve local communities. They will provide Queensland with a means of implementing reforms in regard to water resource allocations and entitlements that have been recommended by COAG (Department of Natural Resources 1997a, 1997b).

It is anticipated that the WAMP process will provide a basis for defining water allocations in major catchments, including the identification of environmental flow requirements (Water Infrastructure Taskforce 1997).

Landcare

A review of ICM and Landcare arrangements has been conducted, in order to interlink Landcare and ICM activities within a simple framework (Department of Natural Resources 1997c)

WaterWise

DNR's WaterWise program is an education and extension program concerning water consumption

Saltwatch, Pasturewatch

Saltwatch and Pasturewatch are school-based monitoring and education programs.

Other relevant state policies/programs include:

Queensland Water Conservation Strategy (Department of Natural Resources 1996)

APPENDIX 3. WATERCOURSE PROTECTION GUIDELINES FOR HOOP PINE AND EXOTIC PINE

The following tables have been extracted from DPI Forestry's silvicultural manuals for hoop pine and exotic pine (DPI Forestry 1996, DPI Forestry 1995).

(I) HOOP PINE GUIDELINES FOR MINIMUM WATERCOURSE PROTECTION ZONES APPLICABLE TO EACH WATERCOURSE CATEGORY

Type of water course	Minimum stream protection zone
Stream *large* (10 m or more wide) *small*	Retain vegetation as a protection zone to extend 20 m each side of the stream bank. Avoid machine disturbance. Vegetation protection zone to extend 10 m each side of the stream bank. Avoid machine disturbance.
Gullies *major* *minor* *major and minor*	Retain vegetation as a protection zone to extend 5 m each side of the high bank. Avoid machine disturbance. Wherever possible, exclude harvesting and site preparation machine disturbance 2 m each side of the high banks, or for 5 m each side of the gully bed where banks are ill-defined. Exclude placement of heaps to be burnt within 10 m of gully edge. Where exclusion of fire has not been achieved, such areas should be re-established as soon as possible with a perennial grass established vegetatively when soil moisture is adequate. Apart from exceptional cases (as approved by the District Manager) exclude hoop pine re-plantingplanting within the managed watercourse protection zone. Extend the above-mentioned watercourse protection measures at least upslope to the minor gully 'run off confluence point" (variously known as the 'primary stream head hollow', 'nick point', 'head cut', 'key hole' or 'inflex point'!) Note: For second rotation design, where existing protection zones exceed the minimum widths stated above they should be preserved in their entirety.
Waterways *unstable* *stable*	Waterways showing signs of active gully erosion or instability should be classified as 'unstable' and protected the same as for minor gullies above. Restrict machine disturbance to designated points along the length of the waterway upslope to the 'run off' confluence point. Exclude all debris stacks intended to be burnt from within 10 m of the waterway bed. On gentle slopes with moderate to high erodibility soil types and good tractor access, planting lanes through waterways can be created using the Silvan mower (where available). In areas with slopes less than 25 degrees and low to moderate erodibility, soil types which can be site prepared by light pushing and burning, retain a light protective unburnt cover of logging debris. Where broadcast burning is used, rapidly regenerate waterways with various cereal and perennial grass crops. Establish perennial grass crops vegetatively and fertilise. Plant hoop pine through stable waterways at direct regime spacings (at least 3 m between trees) and ring tend rather than band tend.

(II) EXOTIC PINE GUIDELINES FOR MINIMUM STREAM PROTECTION ZONES APPLICABLE TO EACH WATERCOURSE CATEGORY

Type of water course	Minimum Stream Protection Zone
Stream large (10 m + wide) small	Retain vegetation as a protection zone to extend 20 m each side of the stream bank. Avoid machine disturbance. Retain vegetation as a protection zone to extend 10 m each side of the stream bank. Avoid machine disturbance. Note: Swampy areas which do not have well-defined banks, which pond water for more than two weeks following normal summer rain, and which release runoff water slowly are classed as major waterways, not streams. Swampy areas which connect a series of lagoons are however classed as streams.
Stream *large* (10 m + wide) *small*	Retain vegetation as a protection zone to extend 20 m each side of the stream bank. Avoid machine disturbance. Retain vegetation as a protection zone to extend 10 m each side of the stream bank. Avoid machine disturbance. **Note:** Swampy areas which do not have well-defined banks, which pond water for more than two weeks following normal summer rain, and which release runoff water slowly are classed as major waterways, not streams. Swampy areas which connect a series of lagoons are however classed as streams.
Gullies *major* (>more than 2 m deep from floor to high bank) *minor*	Retain vegetation as a protection zone to extend 5 m each side of the high bank. Avoid machine disturbance. Wherever possible, exclude harvesting and site preparation machine disturbance 3 m each side of the high banks, or for 5 m each side of the gully bed where banks are ill defined. **Note:** For second rotation design, protection zones that exceed the minimum widths stated above should be preserved in their entirety.
Waterways *major* (stream bed 10 m or more wide) *minor*	Protection zone to extend 5 m each side of the edge of the waterway base. These may be difficult to define prior to harvesting. They may be replanted, or they may be used as grass waterways. Excessive disturbance from clearing, heaping and burning and cultivation however should be avoided.
Anabranch systems and complex watercourses	The anabranch system may be considered as a separate watercourse. The protection zone should be extended beyond the outermost anabranch. The width of the zone should be at least that appropriate to the outermost watercourses, but should be widened if the zone for an inner watercourse would extend further.
Backwater channels	Buffer strips to extend 2 m each side of any discernible high bank.
Overflow areas	These areas will be harvested and re-established using special ‘sensitive area’ management systems.

APPENDIX 4. SOIL ERODIBILITY CLASSIFICATION FOR NATIVE HARDWOOD FORESTS

THE FOLLOWING TABLE HAS BEEN EXTRACTED FROM DPI FORESTRY'S HARVESTING GUIDELINES - NATIVE HARDWOODS (DPI FORESTRY 1995B).

EROSION HAZARD RATING*	SOIL TYPE		PARENT MATERIAL#
	Surface Texture and Subsoil Colour	Soil Groups	
HIGH	Shallow gravelly soils Sands or sandy loams with yellow, pale grey or black subsoils (or derived from granitic material) Loams or clay loams with pale grey or black subsoils	lithosols alluvials, podzols, siliceous sands soloths, solodized solonetz, grey podzolics	Course textured igneous rocks, (granites, granodiorite, diorite, gabbro). Deeply weathered sandstones
MODERATE	Sands or sandy loams with red subsoils (except on granitic material, then erosion hazard rating is high). Loams or clay loams with red or yellow subsoils. Clays with yellow, grey or black colours	red earths red podzolics red or yellow podzolics black earths, grey or brown clays, prairie soils	Sedimentary rocks (shales, mudstones, conglomerates, lightly weathered sandstones). Moderately hard metamorphics
LOW	Clay with yellow subsoils Clay with red subsoils	xanthozem euchrozem krasnozem	Fine textured igneous rocks (basalt, andesite, rhyolite, trachyte Hard metamorphics

* More detailed rankings can be found in the Exotic Pine or the 2R Hoop Pine manuals.

Refers to the erosion hazard of exposed weathered material other than true soil. It is not implied that the above soils are derived directly from the rocks in the adjoining column.

APPENDIX 5. AREAS IN WHICH HARVESTING IS RESTRICTED FOR NATIVE HARDWOOD FORESTS

THE FOLLOWING TABLE HAS BEEN DERIVED FROM DPI FORESTRY'S HARVESTING GUIDELINES - NATIVE HARDWOODS (DPI FORESTRY 1995B).

1. BUFFER STRIPS	Buffer strips are to be retained on each side of designated watercourses, generally commencing at the top of the banks confining the normal flow of the watercourse, however where steeply incised banks are associated with peak water flow on major river systems, these buffer strips may be inadequate or inappropriate. In such instances the point of commencement of the buffer strip may be varied at the discretion of the District Forester and should be commensurate with soil erodibility, frequency of peak water flows and bank stability.
Management of buffer strips shall comply with the following principles: (i) Designated permanent watercourse in Coastal Forests	Mechanical soil disturbance shall not occur within 10 m of a designated permanent watercourse, unless required for stream crossings or haulage roads, as specified in the harvesting plan. Wider reserves, of up to 30 m may be specified by the District Forester on highly erodible or steep sites. Within this buffer strip no tree whose head cannot reasonably be directed to fall out of the strip shall be felled. Harvesting debris from tree felling shall be removed from within the banks of the watercourse as soon as snigging machinery becomes available. Any harvesting debris arising from snigging operations shall also be removed from the banks of the watercourse. Where specified in the harvesting plan, heads of trees fallen on the flood plain of a designated permanent watercourse shall be stacked by the harvesting contractor with as little soil disturbance as possible and disposed of by burning.
(ii) Designated minor permanent and designated intermittent watercourse in Coastal Forests	Mechanical soil disturbance shall not occur within 10 m of designated minor permanent or designated intermittent watercourse, unless necessary for stream crossings or haulage roads as specified in the harvest plan Where possible, trees should be felled so that their heads fall more than 10 m from the stream, and avoid regeneration or retained advanced growth. However where tree lean or the presence of growing stock limit the felling options, the forest officer may authorise felling in the direction which has the least overall impact on the forest environment.
2. OPERATIONAL LIMITS	Access for conventional ground based harvesting systems is limited on the basis of environmental considerations. Slope, soil conditions and soil moisture all interact to predispose soils to damage by harvesting machinery. Access for machinery currently employed in harvesting operations is restricted to slopes not exceeding 30 degrees. Machine operations on moderate (high) erosion hazard soil types with slopes exceeding 25 degrees (20) should be undertaken with a minimum of disturbance to the mineral soil.

REFERENCES

Australian Rural Research In Progress (ARRIP). ARRIP is a database produced by Infoscan Pty Ltd. 1984-July 1997. Copyright in ARRIP content and structure is held by SCARM, and the rural research and development corporations, 1984 to 1997. In: Agriculture & Natural Resources (a database; copyright held by RMIT, 1996-1997)

Australian Bureau of Statistics 1997, *Queensland Year Book 1997*, Australian Bureau of Statistics, Brisbane.

Australian Water Resources Council 1975, *Groundwater Resources of Australia,* AGPS, Canberra.

Australian Water Resources Council 1985, ÎStatus of recreational use of urban water supply storages / catchments Ò BrisbaneÌ, in *Proceedings of the Workshop on the recreational use of urban water storages and their environs, Griffith University, Brisbane, 3-5 December 1984,* Department of Resources and Energy / Australian Water Resources Council, AWRC Conference Series No. 11, AGPS, Canberra, pp. 5Ò6.

Baird, R.W. & Richardson, C.W. 1969, ÎEffects of conservation treatments on water yieldÌ, in *Effects of Watershed Changes on Streamflow*, eds Moore, W.L. & Morgan, C., University of Texas Press.

Bosch, J.M. & Hewlett, J.D. 1982, ÎA review of catchment experiments to determine the effects of vegetation changes on water yield and evapotranspirationÌ, *Journal of Hydrology*, vol. 55, pp. 44-45.

Brown, J.A.H. 1983, *AustraliaÃs Surface Water Resources: Water 2000 - Consultants Report No. 1*. Department of Resources and Energy. AGPS, Canberra.

Cassells, D.S. 1984, 'Forest and water: Just what is known?' *Queensland Agricultural Journal*, vol. 110, no. 1, pp. 49-53.

Cassells, D.S., Gilmour D.A. & Gordon, P. 1982, ÎThe impact of plantation forestry on stream sedimentation in tropical and sub-tropical Queensland Ò An initial assessmentÌ, in *Conference on Agricultural Engineering, Armidale, 22-24 August 1982*, The Institution of Engineers, Australia.

Centre for International Economics. 1997, 'A plan to achieve the Plantations 2020 Vision' - a consultancy report in *Plantations for Australia - The 2020 Vision*. Plantation 2020 Vision Implementation Committee.

Cornish, P.M. 1993, 'The effects of logging and forest regeneration on water yields in a moist eucalypt forest in New South Wales, Australia', *Journal of Hydrology*, vol. 150, no. 2-4, pp. 301-322.

Costantini, A. 1995, 'Impacts of *Pinus* plantation management on selected physical properties of soils in the coastal lowlands of southeast Queensland, Australia', *Commonwealth Forestry Review*, vol. 74, no. 3, pp. 211-223.

Costantini, A. 1989, 'Definition of a plant zone for weed management during the establishment of *Araucaria cunninghamii* plantations', *Forest Ecology and Management,* vol. 29, pp. 15-27.

Costantini, A. & Gilmour, D.A. 1993, 'Some thoughts towards a research strategy for sustainable forest management'. Paper to Sustainable Forestry in Australia: Future Directions Conference. Armidale. 7-10 February 1993. 10pp.

Costantini, A., Grimmett, J.L. & Dunn, G.M. 1997a, 'Towards sustainable management of forest plantations in south-east Queensland. 1: Logging and understorey residue management between rotations in steep *Araucaria cunninghamii* plantations', *Australian Forestry*, vol. 60, no. 4, pp. 218-225.

Costantini, A., Dunn, G.M. & Grimmett, J.L 1997b, 'Towards sustainable management of forest plantations in south-east Queensland. II: Protecting soil and water values during second rotation *Pinus* plantation management', *Australian Forestry,* vol. 60, no. 4, pp. 226-232.

Costantini, A., Dawes, W.R., O'Loughlin, E. & Vertessy, R. 1993a, 'Hoop pine plantation management in Queensland I: Gully erosion hazard prediction and watercourse classification', *Australian Journal of Soil and Water Conservation*, vol. 6, no. 1, pp 35-39.

Costantini, A., Hiley, G., Last, I. & West, D. 1993b, 'Hoop pine plantation management in Queensland II: Watercourse protection', *Australian Journal of Soil and Water Conservation*, vol. 6, no. 1, pp. 40-43.

Costantini, A., Nester, M.R. & Barnes, D.S. 1993c, *Erosion pin research studies in the hoop pine plantations of south-east Queensland,* Queensland Department of Primary Industries Forest Service, Research Note no. 48, 11pp.

Costantini, A., Rose, C.W. & Ciesiolka, C.A.A. 1991, 'Hydrological instrumentation and methodology for hillslope soil loss studies in steepland forestry and tree farming', in *Challenges For Sustainable Development - International Hydrology and Water Resources Symposium, Perth 2-4 Oct 1991*, Preprints. Institution of Engineers Australia, pp. 165-170.

Cresswell, D.J. 1991, Integrated management of farm dams in the Barossa Valley. South Australia, Engineering and Water Supply Department, ESW 87/54.

Department of Natural Resources 1998a, *Code of Practice for Plantations for Wood Production,* Department of Natural Resources, Brisbane.

Department of Natural Resources 1998b, *Code of Environmental Practice for Native Forest Timber Production,* Department of Natural Resources, Brisbane.

Department of Natural Resources 1997a, *Water Allocation and Management Planning,* Department of Natural Resources, Brisbane.

Department of Natural Resources 1997b, *Water Management Planning - Working in Partnership with the Community,* Department of Natural Resources, Brisbane.

Department of Natural Resources 1997c, *Review of Integrated Catchment Management and Landcare Arrangements - Report and Recommendations Paper,* Department of Natural Resources, Brisbane.

Department of Natural Resources 1996, 'Information Paper - Based on the State Water Conservation Strategy', in *Final Report to the Minister for Natural Resources*, Water Infrastructure Task Force, 1997, pp. 116-141.

Department of Primary Industries 1994, *The Sustainable Use and Management of QueenslandÃs Natural Resources: Policies and Strategies - A Discussion Paper*, Department of Primary Industries, Brisbane.

Department of Primary Industries 1993, *The Condition of the River Catchments in Queensland: A Broad Overview of Catchment Management Issues*, Department of Primary Industries, Brisbane.

Department of Primary Industries 1991, *Integrated Catchment Management: A Strategy for Achieving Sustainable and Balanced Use of Land, Water and Related Biological Resources*, Department of Primary Industries, Brisbane.

Dissmeyer, G.E. & Foster, G.R. 1980, *A Guide for Predicting Sheet and Rill Erosion on Forest Land*, U.S. Department of Agriculture, Tech. Publ. SA-TP 11.

DPI Forestry 1996, 'Plantation Design - Exotic Pine Plantations' in *Silvicultural Manual* vol. 4, section 42.

DPI Forestry 1995a, 'Plantation Design - Hoop Pine Plantations' in *Silvicultural Manual* vol. 5, section 52.

DPI Forestry 1995b, 'Harvesting Guidelines - Native Forests', in *Harvesting, Marketing and Resource Management Manual*, section 41.

DPI Forestry 1995c, *Harvesting, Marketing and Resource Management Manual*.

Erskine, W.D. 1992, *An Investigation of Sediment Sources in the Genoa River Catchment, Mallacoota*, East Gippsland River Management Board.

Foster, P.G. & Costantini, A. 1991a, '*Pinus* plantation establishment in Queensland: 1. Field surveys for site preparation, planning and site design', *Australian Forestry*, vol. 54, no. 1&2, pp. 75-82.

Foster, P.G. & Costantini, A. 1991b, '*Pinus* plantation establishment in Queensland: 2. Site preparation classes', *Australian Forestry*, vol. 54, no. 1&2, pp. 83-89.

Foster, P.G. & Costantini, A. 1991c, '*Pinus* plantation establishment in Queensland: 3. Site preparation design', *Australian Forestry*,vol. 54, no. 1&2, pp. 90-94.

Good, R.K. 1992, *The Impact of Development on Streamflow in the Marne River, South Australia*, Engineering and Water Supply Department. ESW 92/23.

Government of Queensland 1990, *AustraliaÃs Forest and Timber Resources - A Queensland Government Submission to the Resource Assessment Commission, Final Draft*, pp. 83-88.

Greacen, E.L. & Sands, R. 1980, 'Compaction of forest soils: a review', *Australian Journal of Soil Research*, vol. 18, pp. 163-189.

Harper, P. B. & S. T. Lacey 1997, *A Review of the Findings from the Yambulla Catchments Forest Hydrology Research Project 1977-1990*, Research Paper No. 33, State Forests of NSW, West Pennant Hills, NSW.

Haydon, S.R., Jayasuriya, M.D.A. & OÃShaughnessy, P.S. 1991, *The Effect of Vehicle Use and Road Maintenance on Erosion from Unsealed Roads in Forests: the Road 11 Experiment*, Melbourne Water, report, no. MMBW-W-0018.

Hughes, K.K. 1984, Trees and salinity, *Queensland Agricultural Journal*, vol. 110, January 1984, pp. 13- 14.

Mackay, S.M. 1989, 'Summary of erosion and hydrological research', in *Hydrology and Forest Practice Workshop*, Forestry Commission of NSW.

Mackay, S.M. & Cornish P.M. 1982, 'Effect of wildfire and logging on the hydrology of small catchments near Eden, NSW, in *The First National Symposium on Forest Hydrology*, The Institution of Engineers, Australia, pp. 111-117.

Managing AustraliaÃs Inland Waters. 1996, A paper prepared by an independent working group for consideration by the Prime MinisterÃs Science and Engineering Council, Department of Industry, Science and Tourism.

Moore, I.D., Burch, G.J. & Wallbrink, P.J. 1986, 'Preferential flow and hydraulic conductivity of forest soils', *Journal of the Soil Science Society of America*, vol. 50, pp. 876-881.

National Forest Inventory 1997, *National Plantation Inventory of Australia*, Bureau of Resource Sciences, Canberra.

National Forest Policy Statement 1992, *National Forest Policy Statement: A New Focus for AustraliaÃs Forests*, Second Edition. AGPS.

Neil, D.T. & Fogarty, P. 1991, 'Land use and sediment yield on the tablelands of New South Wales', *Australian Journal of Soil and Water Conservation*, vol. 4, no. 2, pp. 33-39.

Ockenden, A.P. & Kotwicki, V. 1982, *The Effects of Farm Dams on Flows in the Northern Para River*, report no. 82/59, Engineering and Water Supply Department.

Olive, L.J. & Rieger, W.A. 1987, *Eden Catchment Project: Sediment Transport and Catchment Disturbance 1977-1983*, Monograph series No.1, Department of Geography and Oceanography, University College, Australian Defence Force Academy, Canberra.

OÃShaughnessy, P.J. & Jayasuriyah, D. 1987, 'Managing the ash-type forests for water production in Victoria', in *Proceeding of the Institute of Foresters of Australia 1987 Biennial Conference*, Perth.

Prosser, I.P. & Soufi, M. 1997, 'Gully erosion hazard in plantation forestry operations', in *Cooperative Research Centre for Catchment Hydrology, Erosion in Forests Workshop*, Bermagui, 4-6 March 1997.

Queensland Government Inter-Departmental Committee. 1982, *Pumicestone Passage Water Quality and Land Use Study*, Queensland Government Inter-Departmental Committee, vols. 1-4.

Queensland Department of Environment and Heritage 1993, *Draft Integrated Management Strategy for Pumicestone Passage, its Catchment and Bribie Island - Main Report*, Brisbane.

Ring, P.J. & Fisher, I.H. 1985, 'The effects of changes in landuse on runoff from large catchments in the Upper Macintyre Valley, NSW', *Hydrology and Water Resources Symposium*, Sydney, 14-16 May, 1985, pp. 153-158.

Rose, C.W. 1988, 'Research progress on soil erosion processes and a basis for soil conservation practices', in *Soil Erosion Research Methods* (ed. Lal, R.), Soil and Water Conservation Society Publication, Ankey, Iowa, pp. 119-140.

Ruprecht, J.K. & Schofield, N.J. 1989, 'Analysis of streamflow generation following deforestation in southwest Western Australia', *Journal of Hydrology*, vol. 105, pp. 1-17.

Ryan, P.A. & Gilmour, D.A. 1985, 'Potential erosion and nutrient losses in the conversion to the second rotation hoop pine crop', in *Second Rotation Establishment* - Queensland Department of Forestry seminar, April 1985, Gympie, Queensland.

South East Queensland RFA information kit, 1997

Simpson, J.A. & Grant, M.J. 1991, *Exotic Pine Fertiliser Practice and its Development in Queensland*, Queensland Forest Service, Technical Paper, no. 49.

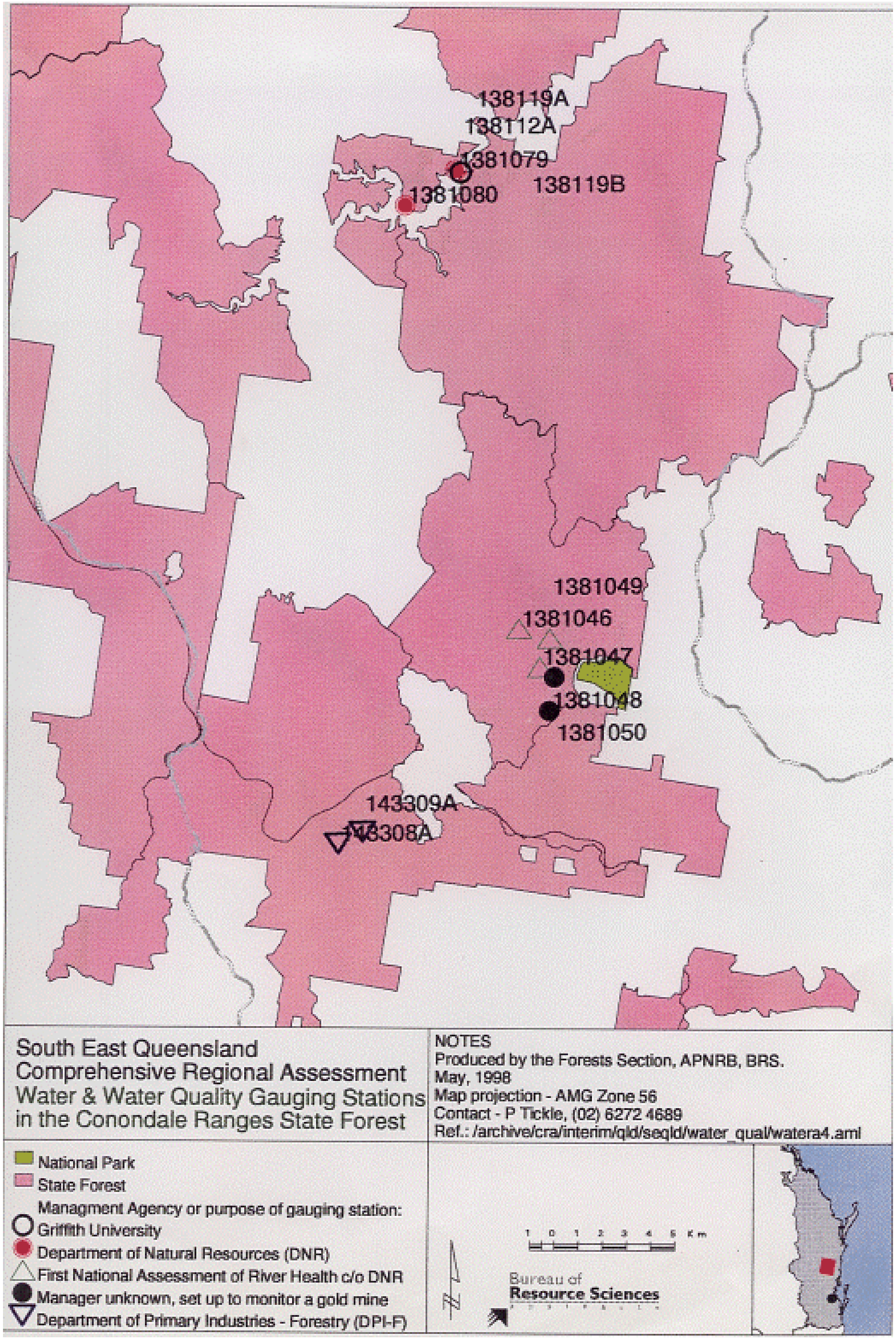
Stirzaker, R., OÃConnell, D. & Prinsley, R. 1996, *Agroforestry and Hydrology - What Do We Need to Know?*, Report on the Agroforestry and Hydrology Workshop. Kurrajong Hotel, Canberra, 11-12 June 1996, Rural Industries Research and Development Corporation, Canberra.

Water Infrastructure Task Force 1997, *Final Report to the Minister for Natural Resources.*

Williams, R.D. & Mackay, S.M. 1988, 'Hydrology and water quality of Tantawangalo catchment', *Forest Ecology and Management*.

Wischmeier,W.H. & Smith, D.D. 1978, *Predicting Rainfall Erosion Losses - A Guide to Conservation Planning*, U.S. Department of Agriculture, Handbook 537.

Wronski and Associates 1993, *Tantawangalo Research Catchments: Changes in Water Yield After Logging*, Forestry Commission of NSW.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South East Queensland
Comprehensive Regional Assessment
Water & Water Quality Gauging Stations
in the Conondale Ranges State Forest
NOTES
Produced by the Forests Section, APNRB, BRS.
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National Park
State Forest
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Griffith University
Department of Natural Resources (DNR)
First National Assessment of River Health c/o DNR
Manager unknown, set up to monitor a gold mine
Department of Primary Industries - Forestry (DPI-F)
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