Chapter 9. Fuelwood management in southern New England
II. Agroforestry

9.1. Introduction

Agroforestry (farm forestry) is a developing arm of Australian agriculture in which tree crops are planted on farmland to increase farm income through provision of various forest products and values such as timber, shade and shelter, fodder, erosion control and water quality (Anon. 1985; Reid and Wilson 1985; Swain 1988; Anderson 1990; Scott 1990; Moore 1992; Mead 1995). It has the potential to become a widespread, profitable and sustainable land use (Prinsley 1991) and is advocated as a component of sustainable fuelwood production in southern New England.

Given an average MAI of 10 $t.ha^{-1}.yr^{-1}$ of New England plantings dominated by *Eucalyptus*, *Acacia* and *Casuarina* spp. (Chapter 7), 2500 ha of tree plantations on farms could meet Armidale's long-term fuelwood demand. This would require a 'bottom up' approach (Arnold 1983; Soussan 1991) in which hundreds of woodlots, shelterbelts and riparian plantings were established on rural properties. Planted woodlots managed on a short-rotation coppice basis would allow a shorter period for return on investment (Wise and Pitman 1981), and could provide more predictable products and yields, shorter rotation times and reduced logging costs (Birk and Turner 1992). Several studies have indicated superior growth in intensively managed eucalypt plantations as compared with natural eucalypt regeneration (Turnbull *et al.* 1988; Birk and Turner 1992). Low-intensity harvesting of fuelwood forests (Chapter 8) could afford time to establish a workable plantation strategy from which most fuelwood could be extracted in the medium to long term.

Opie *et al.* (1984) defined a 'silvicultural regime' as a set of treatments applied to a plantation throughout a rotation, encompassing species and site selection, establishment technique, initial stocking density, thinning, pruning and harvesting. In this chapter, the silvicultural options for fuelwood plantations on the Northern Tablelands are investigated using literature and local experience. A list of recommended species is compiled from a review of wood burning quality and frost tolerance, and site selection criteria are discussed with respect to topography, pedology and landscape ecology. Tree establishment techniques are reviewed and aspects of coppice management, tree spacing, thinning and pruning, fertilising, grazing and harvesting are investigated. Two production scenarios are subsequently developed; on-farm production from shelterbelts and commercial production from coppice plantations. The costs and benefits of each are analysed, and an economic evaluation of the commercial enterprise is conducted under various scenarios. Financial impediments to fuelwood plantations are discussed and mechanisms for promotion are outlined.

9.2. Species and site selection

9.2.1. Species selection

Preamble

There are various environmental and socio-economic factors to consider in choosing fuelwood species, including combustion characteristics, climatic compatibility, growth rate, growth form, nitrogen fixing capacity, coppicing potential, ecological desirability and cultural suitability (e.g. Boland and Turnbull 1981; Midgley *et al.* 1986). Several species lists have been compiled to indicate the potential uses of species and the natural environments to which they are restricted (e.g. Anon. 1990b; Simpfendorfer 1992). A list of species offering potential for fuelwood production on the Northern Tablelands, based on fuelwood suitability and frost tolerance, is presented.

Fuelwood suitability

Selection of fuelwood species is more flexible than selection of sawlog or pulpwood species because the problems associated with end-splitting, warping, shrinkage, collapse, knotting, fibre characters and tree size are irrelevant. Fuelwood desirability is based principally on timber density (Groves and Chivuya 1989) (section 2.2.5). Calorific value, chemical composition and moisture content are not relevant if well-seasoned wood is used. Calorific content of air-dry timber varies little between species and moisture content can be standardised across species using appropriate seasoning techniques (Bhatt and Todaria 1992). For use as household fuelwood, timber must be easy to handle (cut and split) and free from thorns and excessive branchiness (Burley 1980).

Whilst a number of quantitative factors can be used to select fuelwood species including combustion rate, degree of sparking and spitting, rate of emissions and extent of formation of persistent residual embers (Groves and Chivuya 1989), the mechanisms for selection should be put into social context. Different cultures have varying reasons for burning fuelwood and may require a timber specific to a particular task. Many rural communities in regions of the developing world use fuelwood and other biomass almost exclusively for cooking, in which low-density wood and crop residues are favoured for prompt food preparation due to rapid ignition rates, high flame output and immediate heat production (Dewees 1989). In cooler temperate regions of the industrialised world, fuelwood is used more for interior heating and high-density, slower-burning species characterised by prolonged heat output are preferred. In the Armidale region, high-density eucalypts are preferred to low-density eucalypts, pines and sawmill offcuts (section 2.5.1). *Acacia* and *Casuarina* spp. are seldomly consumed despite their excellent fuelwood potential (section 7.2.1); they occur in low densities in forest and woodland in the region and are usually undersized (Appendix XXII).

In addition to good growth and firewood characteristics, *Acacia* and *Casuarina* spp. have the added capability of fixing atmospheric nitrogen, thus improving soil nitrogen status. Net annual accumulation of soil nitrogen in a vigorous *A. dealbata* stand in New Zealand was 280 $kg.ha^{-1}$ (Frederick *et al.* 1985b), similar to the value of 290 $kg.ha^{-1}$ for *C. littoralis* in sandstone soils near Sydney (Hannon 1956). The growth rate of non-nitrogen-fixing tree genera may be improved by co-planting with nitrogen fixing species; *E. saligna* and *E. grandis* grown with *A. melanoxylon* were 25% taller and 28% larger in diameter than those grown in pure eucalypt plantations (DeBell *et al.* 1985).

Frost tolerance

Table 9.1 summarises Armidale's monthly records of rainfall, evaporation and temperature. Armidale experiences cold winters, and is susceptible to frost from March to December. Frosts can be locally severe on the Northern Tablelands during clear winter nights, particularly in shallow depressions in rural areas (Thompson 1970; Thomas 1975). Low-lying terrain in the region exhibits poor atmospheric dispersion, promoting katabatic flux of cold dense air, development of temperature inversions, and formation of frost-hollows. Table 9.2 lists frost-tolerant species with good fuelwood potential.

Table 9.1. Summary of Armidale's rainfall, evaporation and temperature records.

			Temperature (°C)					
			Maximum			Minimum		
Month	Rain (mm)	Evap. (mm)	Mean	Extreme [1]	D/Yr [3]	Mean	Extreme [2]	D/Yr [3]
Jan	102.2	173.3	27.1	39.7	15/39	13.7	4.1*	12/89
Feb	86.2	142.5	26.2	37.8	7/52	13.5	3.0*	24/93
Mar	65.8	136.1	24.2	34.4	7/38	11.5	- 0.6	17/18
Apr	46.8	99.3	20.6	31.6	4/86	7.6	- 5.0*	30/82
May	44.2	65.1	16.5	26.7	5/42	4.0	- 8.8*	23/82
June	57.5	46.8	13.2	24.4	2/23	1.8	-11.0*	25/86
July	49.6	51.2	12.4	21.1	28/58	0.6	-10.0	17/18
Aug	48.7	75.6	14.1	25.7	13/46	1.3	- 9.0*	2/82
Sept	51.0	106.2	17.6	28.3	22/28	3.7	- 6.2*	11/87
Oct	67.7	133.0	21.1	32.4	21/88	7.2	- 4.7*	21/86
Nov	79.7	156.9	24.3	36.4	19/44	10.0	- 1.1*	10/91
Dec	88.2	185.7	26.4	37.7	20/38	12.4	- 0.5*	4/87
TOT	787.6	1371.7	20.3			7.3		

1. absolute maximum temperature recorded in each month
2. absolute minimum temperature recorded in each month
3. day and year of occurrence of extreme temperature

* compiled from data at east Armidale met. station using 14 years of records. All other temperature and rainfall data were compiled from over 100 years of climatic records collected at central Armidale met. station. Evaporation data (MAE) were compiled using BIOCLIM analysis (section 5.2.1).

Table 9.2. Frost-tolerant species producing high-quality fuelwood (adapted from Bootle 1983; Anon. 1990b; Simpfendorfer 1992).

Species	Common Name	ADD (kg.m^{-3})
Acacia baileyana F.Muell.	Cootamundra wattle	
A. dealbata Link	Silver wattle	540-720
A. decurrens (J.Wendt.) Willd.	Green wattle	720
A. elata A.Cunn.ex Benth.	Cedar wattle	
A. falciformis DC.	Broad-leaf hickory	
A. filicifolia Cheel.et Welch.	Fern-leaf wattle	
A. floribunda (Vent.) Willd.		
A. glaucescens Willd.	Coast myall	990
A. implexa Benth.	Hickory	800
A. leucoclada Tindale		
A. longifolia (Andr.) Willd.	Sydney golden wattle	660
A. irrorata Sieb.ex Spreng.		830
A. mearnsii de Wild.	Black wattle	550-750
A. melanoxylon R.Br.	Blackwood	640
A. neriifolia A.Cunn.ex Benth.		
A. rubida A.Cunn.		
Angophora floribunda (Sm.)	Rough-barked apple	850
Callitris endlicheri (Parl.) F.M.Bail.	Black cypress pine	710
Casuarina cristata Miq.	Belah	1150
C. cunninghamiana Miq.	River sheoak	770
C. littoralis Salisb.	Black sheoak	
C. luehmannii R.T.Bak.	Bull oak	1050
C. torulosa Ait.	Rose sheoak	920
Eucalyptus agglomerata Maiden	Blue-leaved stringybark	880
E. albens Benth.	White box	
E. andrewsii Maiden (2 ssp.)	New England blackbutt	930
E. blakelyi Maiden	Blakely's red gum	
E. blaxlandii Maiden et Cambage	Blaxland's stringybark	950
E. botryoides Sm.	Southern mahogany	920
E. caliginosa Blakely et McKie	New England stringybark	
E. camaldulensis Dehnh.	River red gum	900
E. cameronii Blakely et McKie	Diehard stringybark	770
E. consideniana Maiden	Yertchuk	930
E. crebra F.Muell.	Narrow-leaved red ironbark	1090
E. cypellocarpa L.Johnson.	Monkey gum	880
E. deanei Maiden	Round-leaved gum	960
E. dunnii Maiden	Dunn's white gum	800
E. eugenioides Seib.ex Spreng.	Thin-leaved stringybark	820-900
E. fastigata Deane et Maiden	Brown barrel	750
E. fibrosa F.Muell.	Broad-leaved red ironbark	1140
E. globoidea Blakely	White stringybark	820-900
E. globulus Labill. (4 *ssp*)	Southern blue gum	900
E. grandis W.Hill ex Maiden	Flooded gum	620-750
E. laevopinea R.T.Bak.	Silvertop stringybark	860
E. leucoxylon F.Muell.	Yellow gum	1010
E. macarthurii Deane and Maiden	Camden woollybutt	
E. macrorhyncha F.Muell.ex Benth.	Red stringybark	900
E. melliodora A.Cunn.ex Schau.	Yellow box	1100
E. microcarpa (Maiden)	Grey box	1120
E. moluccana Roxb.	Grey box	1120
E. muelleriana Howitt	Yellow stringbark	870
E. nitens Maiden	Shining gum	700
E. obliqua L'Herit.	Messmate stringybark	780
E. pilularis Sm.	Blackbutt	900

Table 9.2. cont'd.

Species	Common Name	ADD ($kg.m^{-3}$)
E. punctata DC.	Grey gum	1080
E. racemosa Cav.	Scribbly gum	930
E. rossii R.T.Baker and H.G.Smith.	Scribbly gum	930
E. saligna Sm.	Sydney blue gum	850
E. sclerophylla (Blakely) L.Johnson and D.Blaxell	Scribbly gum	930
E. sideroxylon A.Cunn. ex Woolls.	Red ironbark	1130
E. sieberi L.Johnson.	Silvertop ash	820
E. tereticornis Sm.	Forest red gum	1050
E. youmanii Blakely et McKie	Youman's stringybark	
Acer spp.	Maple	
Alnus spp.	Alder	
Betula spp. Ehrh.	European Birch	640-670
Carya spp.	Hickory	800
Castanea spp.	Chestnut	
Dalbergia melanoxylon Guill.et Perr.	African Blackwood	1200
Maclura pomifera Schneid.	Osage-orange	950
Populus spp.	Poplar	540
Quercus spp.	European oak	700
Salix spp.	Willow	

ADD = air-dry density

Natives or exotics ?

The replacement of native forest by exotic plantations has provoked worldwide debate over declining soil and water quality and habitat destruction and deprivation. Indigenous wildlife is often absent from exotic plantations because the specialised food and shelter requirements and structural complexity offered by native forests are unavailable (Gepp 1985). Unlike large plantations for national production of sawlogs and pulpwood, establishment of plantations on the Northern Tablelands for regional production of fuelwood will involve the replacement of pasture rather than native forest. Arguments concerning the demise of vertebrate fauna have little foundation given the pasture's depauperate diversity of native vertebrates. On the contrary, substitution of sown pastures by exotic trees is likely to benefit native fauna in terms of refuge, nesting and breeding requirements, especially if a species-mix is planted. The relative benefit to wildlife of reforestation with native versus exotic trees is a separate matter, indigenous trees providing a greater diversity and abundance of resources for fauna in areas where the potential for native tree survival is reasonable. Maintenance of landscape values for visual amenity and tourism potential is an important consideration, and Curtis (1991) recommended that the majority of trees planted in New England over the next decade be of local origin.

A factor critical to the success of indigenous tree plantings in the Armidale region is position in the landscape. Eucalypt plantings are likely to fail if established in landscapes containing trees killed or affected by New England dieback (Plate 9.1). Many plantings, demonstrating a capacity for good growth and survival at present, could be severely damaged by another serious episode. Eucalypt saplings cannot be expected to survive multitudes of defoliating insects if the mature trees they replaced were killed in their thousands. This hypothesis is not intended to impede the progress of tree planting in dieback-prone areas; it simply illustrates the need to use alternative species, either non-local eucalypts which have demonstrated resistance to dieback elsewhere, other Australian genera not affected by dieback (e.g. *Acacia* and *Casuarina*) or exotic species such as *Populus*, *Quercus* and *Salix*. Co-planting of native understorey shrubs to attract parasitic insects and insectivorous birds will also ameliorate dieback.

Plate 9.1. Area of severe dieback on the Uralla-Kentucky plains (near site 86). Tree establishment here should employ mixed plantings of frost-tolerant native local and non-local trees and shrubs on upper and midslopes, and exotic plantings lower slopes.

9.2.2. Site selection

Topography

Based on observations during plantation monitoring (Chapter 7), the most important site factor for tree establishment in the New England region appears to be position on slope. Lower slopes and valleys are more susceptible to frequent and severe frosting. Thompson (1970) detected 26 severe frosts (i.e. occurring at temperatures of -3.3°C or less) on the Armidale floodplain from October 1966 to September 1967, yet no comparable frosts were detected on the adjacent North Hill, 100 m above the floodplain. Using a measure of frost free days, Thompson (1970) determined that the plant growing season on North Hill was 53 days longer than in the floodplain. A frost hazard assessment of the type developed by Laughlin and Kalma (1987) for the Southern Tablelands, in which minimum temperature is predicted using point geographical and climatic information, could be developed in the New England region to assist site and species selection. This could prevent tree mortality such as witnessed at site P18 in winter 1994, in which an overnight air temperature of -14°C at ground level top-killed every *A. dealbata* in a 4-year shelterbelt. In addition to frost constraints, soil drainage on lower slopes is generally inferior to that on upper slopes, rendering the former more susceptible to waterlogging.

Pedology

Land-use history in Australia suggests that agriculture has taken precedence over forestry on highly productive soils. Lunney (1991) contended that Australian forests constitute the 'poorer half of what existed in 1788', and advocated a system of restoration to reverse the losses of 200 years. Carron (1985) reported a history of tree planting on 'crown wasteland' and 'derelict farmland' and Hansard *et al.* (1990) argued that land-use regulations which restrict plantation development to marginal land will ultimately reduce private plantation investments and may create institutional impediments to planting. Most of the productive basalt-derived soils on the New England Tablelands have been cleared for pasture production, and trees are seldomly replanted. While landholders should consider reforestation on basalt, the selection of suitable land is more complex than site productivity alone, and must be integrated within individual property plans and catchment or regional plans.

Landscape ecology

There are ample opportunities to connect existing trees and stands with planted shelterbelts and woodlots given the variegated nature of remnant vegetation on the Northern Tablelands (McIntyre and Barrett 1992), and there are several advantages in doing so. Plantations adjoining natural reserves can act as a physical barrier, reducing the encroachment of air-borne seeds and pests from agricultural land (Davidson 1987) and increasing the effective size of the original island (Harris 1984). Plantations can provide semi-permanent habitat which may improve the conservation status of native birds and mammals if established as a mosaic with native forest and pasture (Woinarski 1979; Suckling 1982; Gepp 1985), and plantings can act as corridors and stopovers to assist in the migration and movement of fauna in the landscape (Breckwoldt 1983, 1986).

Native forest in turn can protect adjoining plantations by moderating the effect of wind, heat and frost during extreme climatic events, and by providing entomological benefits. Integrated pest management, which includes the encouragement of natural population controls through biological control agents such as parasitoids and predators (Ohmart 1990), is often overlooked during site selection and plantation establishment. In reviews of the influence of trees on the abundance of natural enemies of insect pests, Dix *et al.* (1995) emphasised the importance of interfaces (edges) between trees and crops to reduce the need for pesticides while maintaining agricultural productivity, and Abbott (1993) implicated patchiness within plantations as a key factor in minimising insect damage. Scarab beetles *Anoplognathus* spp. are a major pest problem in eucalypt plantations in Australia (Ohmart 1990) and are implicated in rural tree decline on the Northern Tablelands (section 2.2.3). The opportunity for natural control of scarabs by birds (Ford and Bell 1980; Ford 1981,1985), parasitic wasps (Davidson 1984) and arboreal mammals such as sugar glider *Petaurus breviceps* (Suckling 1982) indicates the importance of sympathetic management in native stands on the Northern Tablelands to protect and enhance species richness (Barrett *et al.* 1994), and demonstrates the expedience of establishing multi-species plantations adjacent to healthy stands of native vegetation (Plate 9.2).

Plate 9.2. Part of Winterbourne State Forest (site 121). Local indigenous species (e.g. *A. dealbata*, *E. laevopinea*) could be planted in the adjacent pasture.

9.2.3. Species testing

Screening species listed in Table 9.2. will involve the testing of different provenances in different locations using a series of plantation trials. Burley and Plumptre (1985) described three main stages in the species-testing process. The 'species elimination phase' involves the planting of small plots of species to determine survival and growth over the first few seasons. Several plantations of this nature have been established in the last 10 years by the NAP, NRMS, ERP (section 7.1) and private landholders. A preliminary assessment of growth and survival of various native species was presented in Chapter 7. The 'species testing phase' involves the critical testing or comparison of a number of promising species in larger plots over longer periods and the 'species proving phase' is designed to confirm the superiority of a few promising species under normal planting conditions. Burley and Plumptre (1985) also suggested the testing of species provenance using a 'range-wide provenance sampling phase', a 'restricted provenance sampling phase' and a 'provenance proving phase'.

9.3. Tree establishment

The relatively inexpensive method of direct seeding has generally been unsuccessful in establishing eucalypts on the Northern Tablelands (Curtis 1989; Ford *et al.* 1993); tree planting is the normal practice. Seedlings are grown from seed, 'hardened off' in the nursery as either 'speedlings' or tubestock, then planted in spring or autumn. Speedlings are seedlings grown in small pyramidal cells in moulded plastic trays costing around 30¢.stem^{-1} (Ford *et al.* 1993) compared to $1.00 stem^{-1} for tubestock. The planting site is ripped well before planting, sprayed or scalped to suppress weeds, and fenced from stock to prevent browsing. The seedlings are guarded from frost, wind, rabbits and hares (milk cartons fixed with wooden stakes generally serve this purpose) and preferably watered and fertilised. The combined cost of stakes, cartons and fertiliser to supplement planting is 20¢.stem^{-1} (M. O'Keefe 1995, pers. comm.). Mulching with sawdust is often carried out to suppress weeds and retain soil moisture. This is a relatively labour-intensive and time-consuming activity, and is considered unnecessary given that the growth response of mulched seedlings is often similar to non-mulched seedlings (Curtis 1989; Ford *et al.* 1993).

It was evident from field observation that weed and grass infestation in plantations was the dominant factor inhibiting tree growth on the Northern Tablelands (Chapter 7). Control of vegetation competing for light and water is considered essential for tree growth and survival. An increase in the number of hatching scarab beetles and subsequent damage to young trees is possible if grass is not controlled within plantations (Carne *et al.* 1974). Spraying before planting is the most cost effective way of controlling weeds during the initial growing period. A spraying of 6 L.ha^{-1} Amitrole (non-residual knockdown herbicide), 10 L.ha^{-1} Atrazine (medium term residual pre-emergent herbicide) and 1 L.ha^{-1} wetting agent, mixed with water to a dilution of 500 L.ha^{-1}, is recommended for grassy weed control in all soils except for heavy clays (Neilsen 1990). Pre-planting herbicide costs are about $100 ha^{-1}.

Machine planting is less costly than hand planting (Ford *et al.* 1993). A Chatfield Tree Planter was purchased in June 1990 through the ERP, and is available for hire from the Armidale Tree Group at about $250 day^{-1} (includes operator). The planter has a grader-blade to scalp the soil surface and eliminate the need for pre-emergent chemical weed control. Direct seeding of *Acacia* has been successful on the Tablelands using a Greentech Direct Seeder, which cuts a 30 cm furrow into the soil into which seeds are sprinkled constantly through a small hopper. Direct seeding costs about $160 for the first kilometre, thereafter $120 km^{-1} (M. O'Keefe 1995, pers. comm.)

The protection of trees against livestock and vermin is the most costly activity associated with tree establishment on farms (Campbell 1990). Young shoots are vulnerable to browsing by rabbits and hares (Pearce 1982) and proofing is considered essential for the first two years. To be effective, fencing needs to be constructed from netting or electrified (Neilsen 1990). At $1,800 km^{-1}, netting costs more than a stock-proof fenceline ($1270 km^{-1}; section 8.4.2), and with a $1,400 km^{-1} labour cost (Neilsen 1990), maximum cost of rabbit/stock proof fencing (materials and construction) is about $4,500 km^{-1}. This is higher than estimates given by Neilsen (1990; $2,300 km^{-1}) and Bulman (1991; $2,250 km^{-1}). Cost-saving measures include electrification instead of netting, harvesting timber instead of buying, reuse of old material, and self-labour. Electric fencing is particularly attractive if a non-permanent barrier is required. It is cheaper, faster to erect, more flexible, and more effective in steep or boggy terrain, or where irregular shapes are enclosed (Campbell 1990).

9.4. Plantation silviculture

9.4.1. Coppice management

Regeneration by coppicing has been discussed in Chapters 6 and 8. Most eucalypts coppice readily (Blake 1983; Cremer *et al.* 1990) and most eucalypt plantations grown abroad for fuelwood and pulpwood are managed on a short-rotation coppice basis (Blake 1983; Jones *et al.* 1983; Cremer and Brown 1990). Coppice plantings are usually even-aged, single-purpose tree crops planted with a uniform spacing (Plate 9.3). They utilise intensive management prescriptions which include chemical weed control, fertilising, thinning and pruning. Fertilisers are used to replace nutrients forfeited by regular removal of woody biomass. Slash can be retained after timber extraction to compliment fertiliser application, and nitrogen fixing species may be used to enhance site productivity. Typical coppice rotations (1-15 years) are much shorter than logging rotations (40 to 80 years) in native forest (Pearce 1982), and MAI of coppice stands is usually significantly higher than that of native stands comprising the same species (Pearce 1982). For instance, 30 coppiced neem trees (*Azadirachta indica*) can meet an average family's wood needs in Niger, while ten times as many trees would be required using a non-coppice system (Dang 1993).

The coppice potential of plantation eucalypts has not been investigated in the New England region, although the ability of five naturally-growing eucalypt species to coppice after cutting (Chapter 6) suggests it has a major role to play in plantation management. There is little information on the coppice potential of Australian-grown *Acacia* and *Casuarina* spp. (Boland and Turnbull 1981). The coppicing ability of *Acacia* grown overseas varies considerably between and within species (Davidson 1987). Trees such as *A. cyanophylla* (or *A. saligna*; Tiedeman and Johnson 1992), *A. deanei*, *A. farnesiana*, and *A. pennatula* (Burley 1987) have good coppicing ability; others such as *A. auriculiformis* (Davidson 1987) and *A. mearnsii* (Jones *et al.* 1983) coppice poorly. Some species such as *A. dealbata* sucker from

Plate 9.3.

4-year *E. leucoxylon* coppice plantation for fuelwood production, western Victoria.

(Note the close rows and good weed control. This planting will be grazed until harvesting)

root stock (Boland and Turnbull 1981), a tendency which was observed during tree sampling in New England shelterbelts (Chapter 7). *Casuarina* is able to reproduce by coppicing or suckering (Midgley *et al.* 1981; Boland *et al.* 1992) and many exotic hardwoods including *Acer*, *Alnus*, *Betula*, *Populus*, *Quercus* and *Salix* spp. exhibit good coppicing potential (Blake 1983).

Despite being the type of plantation least compatible with conservation biology (Orians and Millar 1992), the intensively managed coppice woodlot offers several distinct advantages for fuelwood production. The arrangement of plantation trees into rows with uniform and relatively small tree size offers greater opportunity for efficient mechanisation of harvesting operations (Cromer *et al.* 1975), and the even-aged nature of plantations enables harvesting at an age when characteristics are optimal (Wise and Pitman 1981). The cost of replanting after harvesting is avoided (Pearce 1982) and the growth of at least one coppice crop is superior to that of the original planted crop (Blake 1983). Coppice woodlots could reduce indiscriminate fuelwood offtake from native remnant stands, could act as a physical barrier to protect native stands (Davidson 1987), and may be managed for permanent cover to assist in the movement of wildlife. Coppice woodlots could also afford protection for sheep during cold weather. Anderson (1986) considered that a 5-20 ha fenced woodlot with a density of 300-400 stems.ha^{-1} could provide effective shelter after three years.

9.4.2. Tree spacing and configuration

The growth habit of a tree may assist or hinder its manipulation to achieve a desired management objective (Schönau and Coetzee 1989). Closely stocked eucalypt plantations produce tall, slender stems with relatively little branchwood under good growing conditions (Frederick *et al.* 1985a), a characteristic amenable to the intensive production of fuelwood using short rotations. Tree form is less important in fuelwood and pulpwood than in sawlog plantations, and stocking density can be higher providing site productivity is suitable. Lay *et al.* (1987) suggested a density of 900-1600 trees.ha^{-1} for fuelwood plantations in areas of South Australia receiving an MAR of 700-900 mm, and 1400-2000 trees.ha^{-1} in areas receiving over 900 mm. Bartle (1991) reported a density of 800-1000 trees.ha^{-1} for *E. globulus* grown for pulp in a 600-900 mm zone in Western Australia and Kube *et al.* (1987) reported a density of 2200 stems.ha^{-1} for irrigated *E. camaldulensis* in Alice Springs.

Despite exhibiting higher mortality and a lower mean height and diameter per tree than low density plantings, eucalypt plantations with higher stocking densities possess a higher basal area and volume (Opie *et al.* 1984; Schönau and Coetzee 1989). Other advantages include superior form in slower growing species with less apical dominance (e.g. *E. camaldulensis*) and encouragement of natural selection of vigorous plants (Schönau and Coetzee 1989), as well as early suppression of weeds (Stewart *et al.* 1988). Because closely spaced trees may obstruct vehicular access for thinning and harvesting, every few tree lines in a block planting should be separated by about 3 m.

9.4.3. Thinning and pruning

Thinning is carried out to maintain the overall stand performance and vigour of a plantation (Brown and Hall 1968). It concentrates growth in the best performing trees by removing poorly formed or suppressed individuals, and results in larger trees of superior quality, and shorter rotations (Opie *et al.* 1984). Operational decisions regarding the thinning of trees in fuelwood plantations should include consideration of growth factors, tree form and number of main stems. Volume increment is greater in double-stem than single-stem trees (section 7.3.3), and since stem number is not important with regard to the quality or preparation of fuelwood, fast-growing multi-stem trees of good form should be retained.

The first thinning should take place shortly after canopy closure (~ 5 years), and be heavy enough to eliminate all suppressed and poorly formed trees (Schönau and Coetzee 1989). Up to 50% basal area can be thinned initially without reducing gross increment of basal area (Opie *et al.* 1984). Subsequent thinnings should involve trees which display undesirable features such as stem damage or malformation, disease, or slow growth. Even spacing of remaining trees reduces the likeliness of windthrow (Opie *et al.* 1984) and maintenance of canopy closure is desirable to minimise lateral branch growth. Thinning provides an interim salvage harvest, promotes resistance to wind damage and disease, improves amenity and wildlife values, and reduces fire risk (Cremer and Brown 1990). In the absence of thinning, species such as *E. camaldulensis*, *E. maculata* and *E. pilularis* stagnate or 'lock' under heavy competition, and express slow growth and weak dominance (Opie *et al.* 1984).

While pruning is normally undertaken in sawlog-quality plantation trees to eliminate defects caused by knots and to promote clearwood, it is not desirable in eucalypt plantations due to growth suppression and their ability to self-prune (Cremer 1990). However, pruning the inferior stems of coppice regrowth is desirable in eucalypts to encourage growth of the dominant stem(s). Pruning the lower branches of genera other than *Eucalyptus* may also be required to prevent branch interlocking and growth retardance during development of the initial stock. This is desirable for *Acacia* spp. which tend to branch vigorously in early development. Retaining prunings (i.e. small branches, twigs and leaves) *in situ* is desirable in light of investigations into nutrient retention and removal. Retention of unmerchantable biomass in 10-year eucalypt plantations (comprising 15% of total biomass by weight) has returned over 30% of phosphorus, nitrogen and potassium to the soil (Wise and Pitman 1981).

9.4.4. Fertilising

Because the majority of New England soils are deficient in phosphorus, nitrogen and sulphur (McDonald 1968), about 77% of the area is relatively unproductive and pasture production relies heavily upon repeated application of superphosphate (Morgan and Terrey 1990). The use of fertilisers is also important for stimulating growth in eucalypt plantations (Cromer *et al.* 1975,1981,1993; May *et al.* 1975; Cromer and Williams 1982; Schönau and Herbert 1989; Birk and Turner 1992; Stone 1993) and is suggested for the Northern Tablelands. Fertilising encourages rapid early growth and site occupancy to allow seedlings to dominate competing vegetation and escape browsing (Neilsen 1990). About 235 g of superphosphate-ammonium based fertiliser (containing 24.7 g N and 11.3 g P) should be placed about 30 cm from each tree on the soil surface a few weeks after planting (Neilsen 1990). The failure of seedlings to respond to slow-release fertiliser on the Northern Tablelands (Curtis 1989; Ford *et al.* 1993) may have resulted from toxicity caused by contact with roots in the planting hole.

9.4.5. Grazing

Livestock can be introduced to plantings without long-term damage to trees, providing trees have reached a satisfactory height (~ 2 m for sheep; ~ 4 m for cattle) (Plate 9.4). The benefits of grazing in well-established treelots include weed control, natural fertilising, and recycling of fencing material. The pollarding potential of local species should be investigated with respect to grazing in coppice plantations. Pollarding is a form of coppice in which the stem is cut above the browsing height of domestic stock (1-2 m). It allows for grazing and thus weed control in the plantation immediately after harvesting, and negates the need to destock or spray with herbicides.

Plate 9.4.

7-year mixed native shelterbelt site P5.

Cattle intruded after 5 years by breaking down the fenceline (note the health and vigour of the shelterbelt despite low browsing)

9.4.6. Harvesting

While mechanised feller-bunchers and debarkers are increasingly being used for the harvesting and procuring of plantation-grown timbers in Australia and overseas, their adoption for small-scale plantings of the types proposed for the Northern Tablelands is unlikely, and harvesting operations should remain labour intensive as with eucalypts grown on short rotations in other countries (Kerruish 1984). Trees will be felled with chainsaws, cut into 2 to 4 m lengths, transported by road to a storage site, thence split and cut into fuelwood billets for seasoning and subsequent sale. A portable fuelwood mill could be used to cut and section timber on site.

9.5. Fuelwood production from shelterbelts

9.5.1. Introduction

In addition to various non-timber benefits such as shade and shelter for stock and pasture, maintenance of soil and water quality, provision of habitat for native fauna, and increased amenity and land values, farm shelterbelts can be used for timber production (Moore 1986; Bagley 1988; Rensema and Tuskan 1988). The multiple benefits of shelterbelt plantings are reviewed in this section, and a scenario for fuelwood production from a shelterbelt planting on the Northern Tablelands is presented.

9.5.2. Agricultural benefits

Background

The leafy vegetation in a shelterbelt (windbreak, hedgerow, treeline) constitutes a porous barrier which deflects moving air upwards, preventing it from descending again for some distance downwind. Shelterbelts can reduce leeward wind speed by up to 75% of open wind speed (FCNSW 1983; Wakefield 1989), and at a distance of up to 30 times the shelterbelt height (FCNSW 1983; Forman and Gordon 1986; Schroeder and Kort 1989). Shelter increases daily air temperature, relative humidity, soil moisture and soil temperature, and decreases evapotranspiration (Marshall 1967; Forman and Gordon 1986) and evaporation from farm dams (Brown and Hall 1968; Wakefield 1989). It improves irrigation efficiency, increases flexibility in farm management, and enhances landscape and real estate values (Sturrock 1988; Wight 1988). Shelterbelts can increase farm productivity by protecting soil, plants and animals against the physical damage and desiccation of extremes of wind and temperature (Marshall 1967; Lynch and Marshall 1969; Lynch and Donnelly 1980; Carter 1981; Brandle *et al.* 1984; Anderson 1986; Baer 1989; Gregersen *et al.* 1989; Schroeder and Kort 1989; Bird *et al.* 1984,1992). Bird (1988) stated in relation to sheltering effects, "it is clear that if at least 5% of the farm can be devoted to a shelter network then the financial profitability of the farm will be increased in the long term".

Livestock

Excessive heat and cold increase the amount of energy required by livestock to maintain metabolism, reducing the energy available for the production of meat, wool, milk or embryos (Anderson 1986). Cold weather reduces feed efficiency, weight gain, animal health and survival of newborns (Dronen 1988) while heat stress reduces food intake and thus wool growth, and is detrimental to ram fertility, ovulation rate, oestrous duration and conception in ewes, and foetal development (Bird *et al.* 1984; Anderson 1986). Lynch and Donnelly (1980) recorded a 25% increase in the mean annual metabolisable energy intake of sheep in sheltered versus unsheltered paddocks at relatively high stocking densities near Armidale. In an unsheltered environment over several weeks, wool growth in sheep and liveweight gain in cattle can be depressed by 25% and 30%, respectively (Anderson 1986).

Lack of shelter can cause severe stock mortality. More than 100 000 newly shorn sheep died of acute hypothermia in the south-west of Western Australia in a single day in January, 1982, when 100 mm of rainfall combined with a mean temperature of 15°C and a mean windspeed of 11 $km.h^{-1}$ (Reid and Wilson 1985). Heavy sheep losses due to 'cold snaps' have also been reported on the Monaro Tablelands, NSW (Brown and Hall 1968), in western Victoria (Reid and Wilson 1985), and on the Northern Tablelands, NSW (B. Gardner 1995, pers. comm.). Direct stock losses in unsheltered pastures can be very costly: one farmer lost 3400 lambs and 575 ewes at a cost of $53,000 (Reid and Wilson 1985).

Pastures

Wind suppresses plant growth by causing moisture stress and physical damage (Anderson 1986). The benefits of shelter in reducing wind velocity and minimising the effects of advection on crops and pastures were reviewed by Marshall (1967) and Bird *et al.* (1992). Shelter prolongs and enhances plant growth by increasing relative humidity, soil temperature and moisture, reducing evapotranspiration, and preventing desiccation. Shelter can increase production of pasture species (*Phalaris tuberosa* and *Trifolium repens*) by 80 to 110% in the Armidale region (Lynch and Marshall 1969). Sheltered pasture retains biomass longer than unsheltered pasture after the onset of drought, and sheep liveweight is 8-25% greater (Lynch and Marshall 1969; Lynch *et al.* 1980).

Soil

Wind erosion is a serious land degradation problem in most Australian states, responsible for the loss of millions of tonnes of topsoil each year; over 80 000 km^2 of land in NSW alone is severely affected (Eckersley 1989). Yet shelterbelts are seldomly used to reduce soil erosion despite the widespread adoption of windbreak technology overseas (Bird *et al.* 1992). The benefits of shelterbelts in alleviating soil erosion have been demonstrated in the Great Plains of North America (Baer 1989) and the Volga steppes of Russia (Schroeder and Kort 1989). Because the rate of soil erosion is proportional to the wind velocity cubed (Baer 1989), even a modest reduction in wind speed can cause a major reduction in erosion. Bird *et al.* (1992) estimated that the planting of 5% of land to shelterbelts in dry temperate areas in Australia could reduce windspeed by 30 to 50% and soil loss by up to 80%.

9.5.3. Riparian benefits

Use of fertilisers on the Northern Tablelands contributes to the accumulation of water-borne nutrients (principally phosphates and nitrates) responsible for eutrophication and outbreaks of blue-green algae in major river systems in western NSW (Creagh 1992; Alexandra and Eyre 1993). Aerial application of fertiliser such as superphosphate is widely used for enhancing or maintaining the productivity of exotic and natural pastures (McDonald 1968), and represents a diffuse source of water pollution over which there is presently little control. One approach to reducing the problem is establishment of shelterbelts as vegetative buffer zones or filter strips between pollution source areas and receiving waters, designed to intercept and utilise nutrients as they move downslope. A buffer zone is a permanently vegetated parcel of land adjacent to a watercourse which is managed independently from the surrounding rural landscape to retard the movement of sediment and nutrients (Fail *et al.* 1987; Riding and Carter 1992; Muscutt *et al.* 1993; Schultz *et al.* 1995). Woody vegetation with ample ground cover increases the hydraulic roughness and infiltration capacity of the ground surface, reducing the rate and quantity of overland flow and increasing the potential for accumulation of sediments and nutrients in the buffer zone. Sub-surface nitrates are intercepted in the buffer and either assimilated by vegetation or broken down by denitrification (Muscutt *et al.* 1993), and soil erosion by water movement is reduced when shelterbelts are planted along contours (Forman and Gordon 1986). Other benefits include streambank stabilisation, provision of shade for moderating water temperature and regulating aquatic plant growth, supply of organic matter for consumption by aquatic invertebrates, and enhancement of visual appeal and recreational potential (O'Laughlin and Belt 1995).

9.5.4. Design criteria

Upland shelterbelts

There are no stringent rules concerning land ratio of shelterbelts in a pastoral system, the species and species mix used, nor the spacing, stocking density, number of rows and height of trees within. Important design factors are consistent foliage density, to prevent funnelling and turbulence, and shelterbelt length (Reid and Wilson 1985). Several approaches have been used to optimise shelterbelt design. Wen and Wang (1991) employed a ventilation coefficient and windproof efficiency, Dronen (1988) considered climate and type of livestock, and Finch (1988) used the relative tolerance of various field crops to wind and abrasion by air-borne soil particles. To protect livestock and crops, Wen and Wang (1991) advocated a constant breadth of 7.5-10 m using 5-7 rows and FCNSW (1983) suggested a within-row spacing of 2.5-4 m and a between-row spacing of 3-6 m. Multiple rows of tall trees should be supplemented by tall shrubs and small trees on the windward side to maintain foliage to ground level (Carter 1981; FCNSW 1983), and windbreak porosity should ideally be 35 to 50% (Carter 1981). For ideal windbreak performance in grazing land, Dronen (1988) suggested dense foliage from 2-6 m a.g.l. and mid-dense foliage (50% density) above 6 m. Because thinning, pruning and harvesting of trees in a shelterbelt affect its height and density (Bagley 1988), a multiple row shelterbelt with non-timber rows is desirable for maintenance of structural integrity and thus performance. The integrity of lower-storey trees and shrubs should be carefully monitored if livestock are introduced.

Although shelterbelts can reduce windspeed at a distance of up to 30 times the shelterbelt height (FCNSW 1983; Forman and Gordon 1986; Schroeder and Kort 1989), a rule-of-thumb is that the space between shelterbelts should be no more than 20 times the shelterbelt height to provide useful shelter (Brown and Hall 1968) and prevent wind erosion (Carter 1981), with closer inter-belt spacings on steeply sloping terrain (Finch 1988). In areas of variable wind direction, the minimum desirable length of the shelterbelt is 20 times the tree height (Wakefield 1989); in areas of uniform wind direction, length should be 8-12 times the mature height (Dronen 1988). In terms of land area ratio, Wen and Wang (1991) suggested that shelterbelts comprise 5.6-10.5% of agricultural land in China and Schroeder and Kort (1989) cited work in Russia suggesting 2-7%. Literature from Tasmania claimed an optimum coverage of 1-5% for livestock protection, depending on farm productivity and exposure (Dronen 1988). This contrasts with a suggested 10% coverage of shelter in grazing areas of southern Australia where MAR > 600 mm (Bird *et al.* 1992).

Riparian zone plantings

Various papers cited by Fail *et al.* (1987) suggest that replacing older trees with younger, more vigorous trees in riparian environments perpetuates nutrient uptake and enhances water quality. Establishment of a well-planned network of buffer plantations adjacent to major New England watercourses and water storages thus affords potential for integrating urban fuelwood production with enhancement of water quality from heavily fertilised catchments in the region. A dual system featuring an obligatory riparian strip abutting the stream, within which timber cutting is prohibited and stock access limited, and a fuelwood buffer plantation further upslope, is advocated for New England streams and storages (Figure 9.1). The system would remove nutrients under a selective regime of fuelwood cutting and replanting and enhance wildlife refuge status (Harris 1984). The use of exotic or non-local trees may be required in areas subject to severe dieback or frost, and plantings could be designed to incorporate pre-existing remnant trees in lower slope positions. Riparian strips should be of sufficient width to control water and nutrient flows from upslope and facilitate the movement of forest plants and animals adjacent to the stream system (Forman and Gordon 1986). Riparian strips should be 20 to 30 m wide to prevent most silt from entering the stream (Riding and Carter 1992), although strips should be wider where slopes in the riparian zone are steep or soil infiltration rates are low (O'Laughlin and Belt 1995). Widths of 50 m may be required to filter pesticide drift from intensively managed plantations (Barton and Davies 1993).

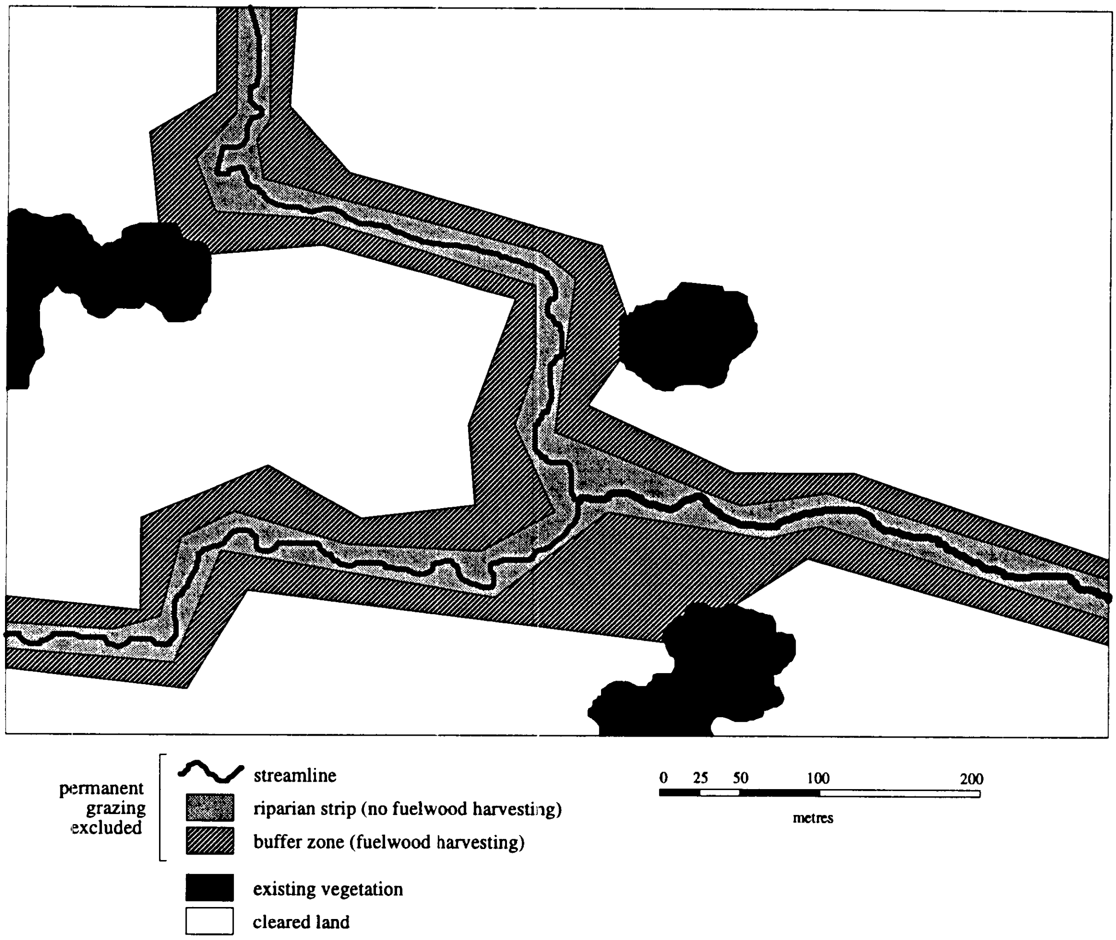


Figure 9.1. Hypothetical design for a riparian fuelwood planting in southern New England.

9.5.5. A production scenario

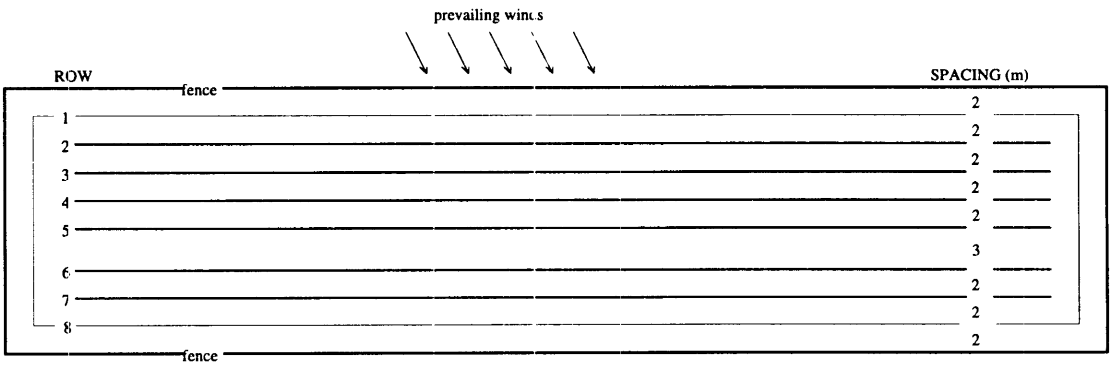
The following scenario considers a New England landholder who intends to use multi-row shelterbelts for self-sufficiency in fuelwood after 8 years. A mixed planting containing equal numbers of *A. dealbata*, *C. cunninghamiana* and *E. sideroxylon* trees will be used over a project life of 20 years. Fuelwood harvesting will commence after 6 years (ready for burning 2 years later after seasoning), and continue every second year until all trees have been felled at year 20. Assuming the landholder consumes 15 $m^3.yr^{-1}$ (roughly equivalent to the average 8.85 $t.yr^{-1}$ used by rural households; section 2.4.2), a total of 30 m^3 will be required from each harvest (240 m^3 from 8 harvests over 14 years). Volume functions established for *A. dealbata*, *C. cunninghamiana* and *E. sideroxylon* (Figure 7.7) assist calculation of the number of trees required at each harvest (Table 9.3). A total of 1833 trees (611 each species) need to survive to ensure supply of 240 m^3 (~ 140 t) of fuelwood over 14 years. Given a survival rate of about 90% for soundly established trees (Curtis 1991), a total of 2037 trees (679 of each species) should be planted.

Table 9.3. Shelterbelt planting requirement for *A. dealbata*, *C. cunninghamiana* and *E. sideroxylon* under a scenario of on-farm self sustainability in firewood.

Years elapsed	No. harvested [1]	Fuelwood volume (m^3)			Total fuelwood volume (m^3)
		Acacia	*Casuarina*	*E. sideroxylon*	
6	229	11.526	9.017	9.468	30.011
8	127	11.442	9.107	9.612	30.161
10	81	11.439	9.176	9.706	30.321
12	56	11.408	9.190	9.732	30.330
14	41	11.380	9.190	9.740	30.310
16	32	11.609	9.390	9.956	30.955
18	25	11.484	9.300	9.863	30.647
20	20	11.346	9.195	9.754	30.295
Total	611	91.634	73.565	77.831	243.03

1. per species

Speedlings are established at a spacing of 2 x 2 m (2500 $trees.ha^{-1}$) using a total of 4074 m of treeline. Two shelterbelts of the specifications outlined in Figure 9.2 are advocated. Rows 1 and 8 contain medium-sized shelter trees and surround the entire shelterbelt. They are hardy species designed to protect timber species, and are maintained at an intra-row spacing of 2 m throughout the life of the shelterbelt. Rows 2-7 are firewood species; containing *A. dealbata* and *C. cunninghamiana* (rows 2-5) and *E. sideroxylon* (rows 6-7).



Specifications : 6 interior rows of 340 m length, each containing 170 fuelwood trees;
2 large rows (345 m) and 2 small rows (15 m) containing a total of 360 non-fuelwood trees;
shelterbelt width = 19 m; shelterbelt length = 350 m; shelterbelt area = 0.665 ha;
length of fenceline = 738 m.

Figure 9.2. An 8-row farm timberbelt providing on-farm fuelwood and shelter (not to scale).

The total cost of establishing two shelterbelts, each containing 1380 trees, and each surrounded by 738 m of fenceline, is estimated to be $10,170 using cost factors listed in Table 9.4. The cost of fencing contributes $6,640 (65.3%) and the cost of purchasing and establishing speedlings, including a day's hire of the Chatfield Planter, is $3,010 (29.6%). Fencing costs could be reduced significantly by avoiding outside labour, by electrifying instead of netting for vermin control, and by cutting fencing timber from the property. There are two major economic benefits associated with fuelwood planting using shelterbelts. First, the landholder saves the cost of paying a wood merchant $750 yr^{-1} (i.e. 8.85 t at $85 for genuine tonne; Chapter 2) in the absence of farm-grown firewood or alternative sources. Second, productivity over an estimated 20 ha of pasture will ultimately benefit from the effects of shelter. While economic evaluation is not attempted here, Kellas and Yule (1991) used the FARMTREE model (Loane 1991) to simulate the net present value (NPV) of a 1000 m timberbelt of *E. leucoxylon* in a 600-700 mm rainfall area in Victoria. The NPV of the agricultural component over a 40 year period was estimated to be +$832. Other benefits include improved amenity and land values, soil and water protection and provision of wildlife habitat.

Table 9.4. Costs associated with tree establishment on the Northern Tablelands.

No.	Activity	Cost
1.	Fencing (includes labour)	$4,500 km^{-1}
2.	Fence maintenance	$50 $km^{-1}.yr^{-1}$
3.	Site preparation (deep ripping and spraying)	$200 ha^{-1}
4.	Establishment cost (nursery and planting costs)	$1 $tree^{-1}$
5.	Chatfield planter	$250 day^{-1}
6.	Direct seeder	$160 for first km; thence $120 km^{-1}
7.	Fertiliser	$250 ha^{-1}
8.	Opportunity cost of grazing exclusion	$50 $ha^{-1}.yr^{-1}$
9.	Opportunity cost of reduced stocking rates	$40 $ha^{-1}.yr^{-1}$
10.	Chainsaw operation	$1.20 t^{-1}
11.	Transport (4-t truck)	$0.30 km^{-1}
12.	Travel distance to Armidale	25 km (one-way)

9.6. Urban fuelwood from a coppice woodlot

9.6.1. Design

The following analysis considers the establishment of a 9 ha tree plantation (300 x 300 m) for production of urban fuelwood over 40 years. It comprises an equal area of *Acacia*, *Casuarina* and *Eucalyptus* spp., with 1000 trees of each genus established in a 1 ha coupe each year for 9 years (3000 $trees.ha^{-1}$). At least 20 different species from Table 9.2 are tested in the first three years of establishment (phase 1), with subsequent plantings from year 4 to 9 (phase 2) using the best performing species. Successful trees such as *A. dealbata, C. cunninghamiana, C. littoralis, E. laevopinea, E. caliginosa, E. melliodora*, and

E. sideroxylon (Chapter 7), are planted in year 1. Establishing trees over 9 years reduces risk of damage caused by extreme climatic or other events, and provides an opportunity to enhance growth rate using species screening. It also enables annuity rather than lump sum payments from fuelwood harvesting and spreads the taxation benefits of tree establishment. The entire plantation site is fenced before planting to ensure control of rabbits and hares, and livestock movement is controlled within the enclosure using electric fencing. No treelots are grazed within 5 years of planting. Thinning and pruning is carried out in spring and harvesting is conducted in autumn. Freshly cut fuelwood is stacked and retained in the field for air-drying prior to sale two seasons later. Most firewood is sold from late summer to late winter.

Table 9.5 shows the silvicultural schedule to be employed. *Acacia* and *Casuarina* spp. are harvested three times in each coupe on a 10-year rotation, with a smaller fourth harvest in coupes 1-5 at the end of the project (year 38). *Eucalyptus* spp. are harvested in each coupe on two 15-year rotations over the 38-year period, with a minor third harvest in coupes 1-5 in year 38. The first rotation of *Acacia* and *Casuarina* is thinned to 1670 stems.ha^{-1} after 5 years; the first rotation of *Eucalyptus* is thinned to 2300 stems.ha^{-1} after 5 years thence 1670 stems.ha^{-1} after 10 years. Coppice pruning involving the removal of minor stems from the coppicing stool of each tree, to retain the best one or two stems, occurs 5 years after harvesting for each genus.

Given that assessment of coppice growth within plantations has not been undertaken on the Northern Tablelands, the potential yield from various genera and species of hardwood grown for fuelwood production is essentially unknown. The variation in growth rates reported elsewhere is large. Jacobs (1955) obtained yields of 1.7 t.ha^{-1}.yr^{-1} from 25-year rotations of eucalypts in coppice experiments near Canberra and French (1982; cited in Jones *et al.* 1983) predicted an average yield of 2.4 t.ha^{-1}.yr^{-1} from dryland coppice rotations in Hamilton, Victoria. Woodlots in high rainfall areas of South Australia (> 900 mm) can reach 20 t.ha^{-1}.yr^{-1} (Kellas and Yule 1991) and a maximum 15 t.ha^{-1}.yr^{-1} has been achieved after 10 years in WA (Moore 1991). Wise and Pitman (1981) considered an MAI range of 11.0-16.2 t.ha^{-1}.yr^{-1} for six *Eucalyptus* species grown in Australia on rotations of 10 years, and Cannell and Smith (1980) considered a range of 7-15 t.ha^{-1}.yr^{-1} for hardwoods in general, managed on 11 to 26-year rotations. Growth increments listed in Table 9.6 were adapted from yield studies in Chapters 6 and 7, and are used in the economic evaluation. A total of 3700 t of firewood is sold over the project life.

9.6.2. Economic evaluation

An impediment to capital investment in tree plantations is intergenerational inequity, in which future income from relatively long-term timber production is discounted heavily. It is symptomatic of what Grut (1987) described as the 'tyranny of compound interest', in which long-term investments are discounted to insignificant values, rendering them unattractive to prospective investors. Discounting biases against future generations, and is inconsistent with the philosophy of sustainability. The higher the discount rate, the lower the importance attached to the future, and hence society has less inclination to

Table 9.5. Silvicultural schedule for a 9 ha fuelwood coppice plantation.

	COUPE (1 ha)																										
	1			2			3			4			5			6			7			8			9		
YEAR	*A*	*C*	*E*	*A*	*C*	*E*	*A*	*C*	*E*	*A*	*C*	*E*	*A*	*C*	*E*	*A*	*C*	*E*	*A*	*C*	*E*	*A*	*C*	*E*	*A*	*C*	*E*
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38																$	$	$									
39																			$	$	$						
40	s	s	s	s	s	s	s	s	s	s	s	s	s	s	s							$	$	$	$	$	$

A = Acacia; C = Casuarina; E = Eucalyptus

s : minor return from thinnings and prunings (and final harvest from coupes 1-5)

$: return from major harvest

Silvicultural Treatment

- None
- Establishment
- Thinning
- Pruning
- Harvest

Table 9.6. Mean annual increments used for different stages of plantation harvesting.

Rotation	Silvicultural activity	Genera	Years elapsed since planting	MAI ($t.ha^{-1}.yr^{-1}$) Phase 1	MAI ($t.ha^{-1}.yr^{-1}$) Phase 2
1	1st thinning	*Acacia*	5	1	1.5
		Casuarina	5	1	1.5
		Eucalyptus	5	1	1.5
	2nd thinning	*Eucalyptus*	10	5	7
	initial harvest	*Acacia*	10	7.5	10.5
		Casuarina	10	8.5	11.5
		Eucalyptus	15	9	12
2	1st coppice pruning	*Acacia*	15	2	2.5
		Casuarina	15	2	2.5
		Eucalyptus	20	3	4
	1st coppice harvest	*Acacia*	20	10	13
		Casuarina	20	11	14
		Eucalyptus	30	12	15
3	2nd coppice pruning	*Acacia*	25	2	2.5
		Casuarina	25	2	2.5
	2nd coppice harvest	*Acacia*	30	10	13
		Casuarina	30	11	14
4	3rd coppice harvest	*Acacia*	37	7.5	-
	(coupe 1)	*Casuarina*	37	8	-
		Eucalyptus	37	8.5	-
	3rd coppice harvest	*Acacia*	36	6	-
	(coupe 2)	*Casuarina*	36	6.5	-
		Eucalyptus	36	7	-
	3rd coppice harvest	*Acacia*	35	5	-
	(coupe 3)	*Casuarina*	35	5	-
		Eucalyptus	35	5.5	-
	3rd coppice harvest	*Acacia*	34	-	4.5
	(coupe 4)	*Casuarina*	34	-	4.5
		Eucalyptus	34	-	5
	3rd coppice harvest	*Acacia*	33	-	3
	(coupe 5)	*Casuarina*	33	-	3
		Eucalyptus	33	-	3

conserve natural resources for future use (Pearce and Turner 1990). Lorrain-Smith (1982) claimed that unless significant events in the distant future are included in cost-benefit calculations, their relevance may be ignored and dubious decisions made; catastrophic disasters or vast benefits are inconsequential if they lie over the time horizon. There is a good case in social cost benefit studies for using a lower 'social discount rate' (e.g. 5%) to compromise the ethical concern for future generations (Loane 1988).

Discount rates of 5, 7, 9 and 11% are adopted in the following analysis, and their effects are illustrated in Figure 9.3. An underlying assumption is that value-adding (harvesting, billeting, splitting and drying) and marketing of firewood is undertaken by the farmer 'free of cost'. Using other cost assumptions listed in Table 9.4, the NPV of the fuelwood plantation is positive after 40 years at discount rates of 5 and 7% (\$603 yr^{-1} and \$141 yr^{-1}, respectively), and negative at 9 and 11% (-\$124 yr^{-1} and -\$279 yr^{-1}, respectively). This is encouraging given that full fencing and establishment costs have been included (\$8,630 in the first year), and that a relatively small price on a delivered tonne of air-dried firewood (\$65 t^{-1}) has been assumed.

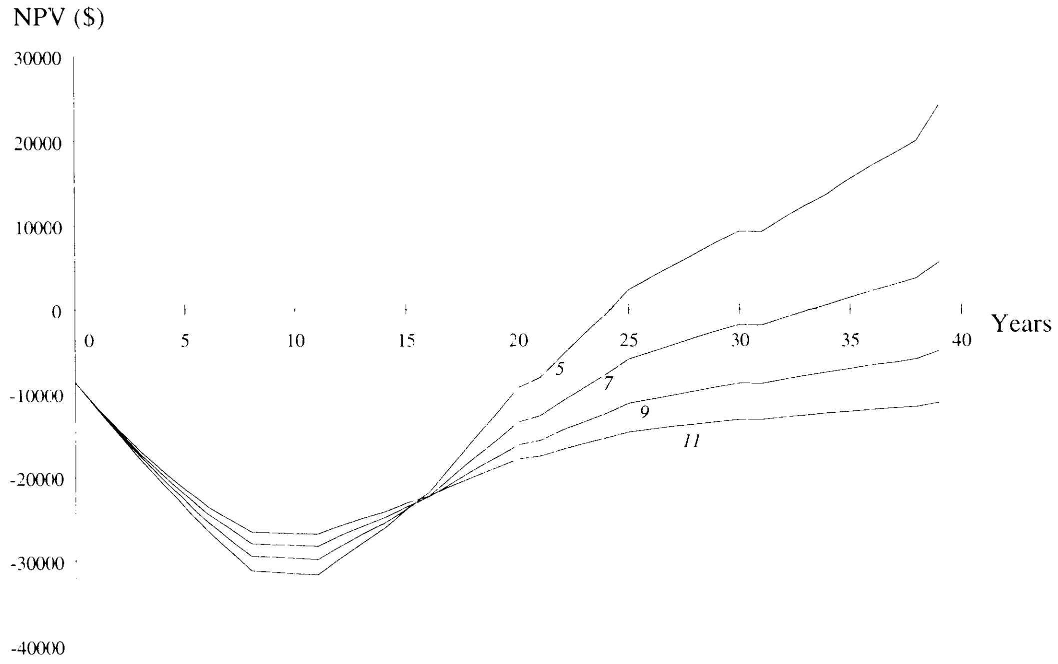

Figure 9.3. Effect of discount rate on NPV and breakeven age in a private fuelwood plantation.

The effect of fuelwood price, transport distance and load capacity on NPV and breakeven age is shown in Figure 9.4. Fuelwood grown 125 km from Armidale and hauled in 1-t loads costs a farmer nearly \$30,000 over 40 years if sale price is \$65 t^{-1}, but at \$105 t^{-1}, the same farmer will profit by just over \$1,000 in 40 years. If the farmer uses a 4-t truck to haul wood from 125 km, she or he will profit by \$22,200 over 40 years at \$105 t^{-1}, and if travel distance is 25 km, the NPV after 40 years will be \$32,700 (~\$820 yr^{-1}). Although \$105 t^{-1} is a possible future price considering increasing awareness of the environmental costs of fuelwood extraction and combustion, \$85 t^{-1} is the current price for 'genuine' tonnes. At \$85 t^{-1}, a coppice plantation 25 km from Armidale has an NPV of \$480 yr^{-1} (4-t vehicle) or \$375 yr^{-1} (1-t vehicle).

Given the large number of assumptions enforced by limited background data and the absence of a means to validate the economic forecasts, some caution is needed in interpreting these results. Growth rates under coppice management have been estimated using a limited set of yield data (Chapters 6 and 7), and grazier's labour has not been costed into the analysis.

Potential losses from royalty payments for non-value-added firewood were predicted by two recent benefit-cost analyses using discount rates of 7%. Stewart and Salmon (1986) found pastoralism to be more profitable than fuelwood plantations under sewage irrigation using a fuelwood royalty of \$2.60 m^{-3} and Moore (1991) calculated the NPV of coppice firewood production in WA over a 30 year period to be \$296-\$3,690, based on fuelwood royalties of \$10-15 m^3. With a typical royalty of \$0-4 t^{-1} and a price of \$65 t^{-1} in Armidale, value-adding would increase the value of firewood by at least 1500%. Where a

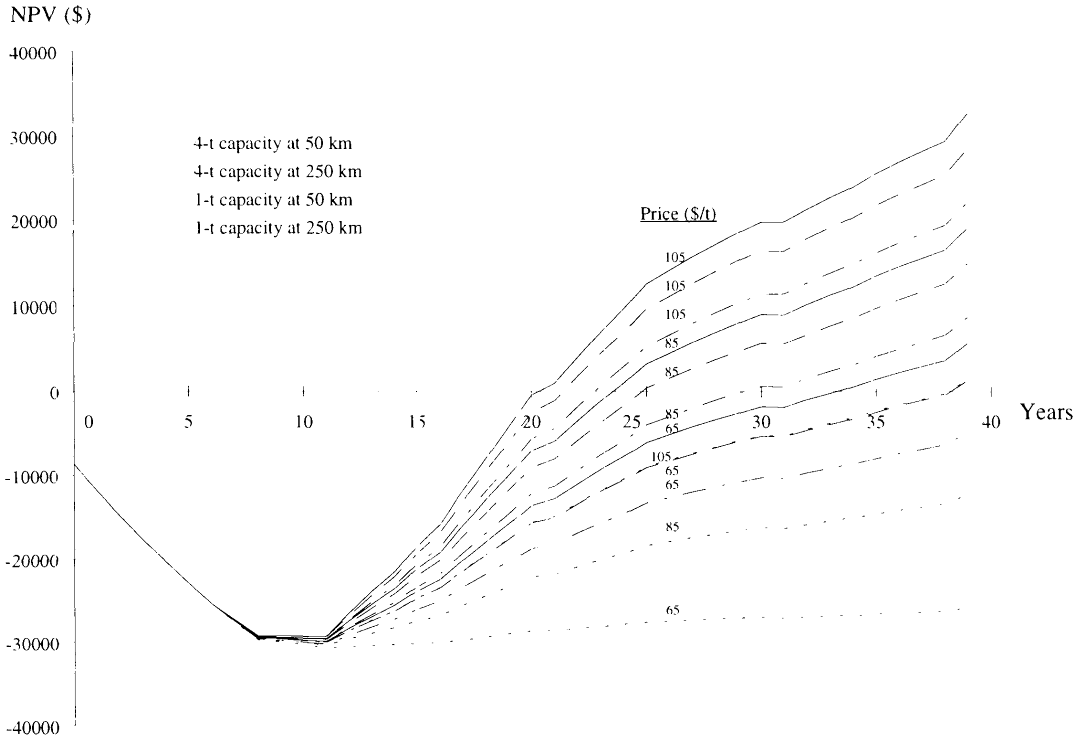

Figure 9.4. Effect of fuelwood price, haulage capacity and travel distance on NPV and breakeven age (using 7% discount rate).

15-year plantation on might be worth $500 to a wood merchant, it is worth $7,500 to a private landholder after value adding. There is an opportunity to diversify farm income by growing firewood if farmers are prepared to allocate labour and capital to plantation establishment and management, estimated for the above scenario at 400 days for planting, thinning, pruning, and harvesting plus 800 trips to market during the project lifetime of 40 years.

Important factors in investment decisions include liquidity (marketability), and time of maturation (Mills 1988). Liquidity is probably the highest risk associated with fuelwood production because alternative fuels and woodsmoke emissions each have the potential to suppress the Armidale market in future. Mills (1988) discussed risk reduction through investment diversification, in which forest investments are part of a landholder's total investment portfolio. On the Northern Tablelands, future investment decisions in tree plantings should be appraised against the farmer's overall investments (usually from sale of wool and beef). Co-production of timber offers flexibility in farm income, especially considering recent sharp increases in the costs of finance, fuel and fertilisers, fluctuating commodity prices and the impact of drought on animal production (Stewart 1988). Plantation trees could be retained during years when wool profits (and taxable income) were high and harvested in years of poor commodity prices (drought and suppressed wool markets) to supplement income. Problems associated with maturation time and timber marketability can also be negated by a shelterbelt's potential to return a positive NPV without sale from fuelwood.

9.7. Public policy

9.7.1. Taxation

Taxation policy plays a major role in private forestry investment decisions in Australia. A tax-payer who engages in forestry operations in Australia is classified as a primary producer, thus most costs associated with plantation establishment and maintenance are tax deductible (Stephens and Hansard 1995) and depreciation at 3% of initial cost per annum is available on fencing costs (Boutland and Byron 1987). Two income modification schemes (the income averaging provisions and the income equalisation deposit scheme), introduced under the taxation system relating to primary production, can be used to alleviate period inequity for private forest investors (Stephens and Hansard 1995). Period inequity refers to the irregular fashion in which investment returns from afforestation ventures are accrued such that 'lump sum' taxes paid on forestry investments are much greater than taxes paid on investments in other industries (e.g. agriculture, mining) in which income is more evenly spread over time (Moore 1992). Period inequity has acted as a deterrent to plantation establishment (Hansard *et al.* 1990), and remains a problem for certain forestry investors despite income modification schemes (Bhati *et al.* 1991).

Another problem for private forestry investment is that public agencies are not required to pay corporate tax for establishing plantations while private companies and individuals are required to pay all government taxes and charges (Stephens and Hansard 1995). This results in substantial savings for government agencies because real costs for land and other inputs for plantations are considerably lower than for the private sector. Lack of competitive neutrality reflects a misallocation of resources and acts as an impediment to commercialisation of private plantations (Bhati *et al.* 1991). Public plantations should operate under full commercial conditions if governments wish to encourage private investment in timber plantations (RAC 1992).

9.7.2. Assistance schemes

To overcome problems associated with the long-term nature of forest investment in the Republic of Ireland, the European Community introduced in 1985 a reimbursement package in which farmers participating in government-funded plantation establishment on private land received an initial grant plus annuity payments for 15 years. The scheme not only demonstrated the capacity of government incentives to establish farm forests where none had previously existed, but increased the total plantation estate from just over 400 ha in 1985 to a projected 30 000 ha in 1993 (Gairdner 1993). Direct assistance measures including government funding, low interest loans, free technical advice and subsidised establishment help to promote positive plantation decisions in Australia. Assistance schemes coupled with a ready market for pulpwood in Tasmania, for example, have had an important bearing on private eucalypt plantations (Wood 1982), with about 2300 ha established by 1984 (Tibbits 1986) and almost 34 000 ha established 10 years later (Rolley 1993).

Most assistance schemes involve joint venture or sharefarming. These are tree planting agreements between investors and landholders which provide the investor with the right to a wood product *profit á prendre* without having to purchase land, and the landholder with a share in the royalties and a possible annuity (Moore 1992). While most joint venture schemes involve products such as sawlogs and pulp-wood for which a market system is in place, governments could finance the establishment of markets for production of lesser wood commodities, such as poles, fencing timber, and fuelwood (Moore 1992). The potential for creating investment opportunities and lucrative markets based on biological diversification across New England farms suggests that investigatory steps be taken. Of interest is the timberbelt sharefarming strategy in which the farmer receives a non-monetary annuity in the form of shelter, and all coppice crops subsequent to the initial harvest belong entirely to the farmer (Bartle 1991). Council schemes could also be drafted in which land rates are subsidised with respect to the acreage of plantation established for fuelwood production in return for benefits such as erosion prevention and improved amenity and tourism potential.

9.8. Conclusions

Prospects for private investment in fuelwood plantations on the Northern Tablelands are encouraging given appropriate market opportunities, fuelwood prices, discount rates and transport distances, and proper species and site selection, tree establishment and plantation silviculture. Similar to fuelwood forestry (Chapter 8), returns are optimised when graziers prepare, market and sell the firewood themselves, although appropriate fuelwood royalties ($\geq$ \$20 t^{-1}) would provide attractive returns if future prices were at least \$85 t^{-1}.

The main recourse for instituting a rise in the price of delivered fuelwood is through regulation of wood merchant activities under licence, in which wood quantity and quality is scrutinised before sale. Fuelwood pricing structure should ultimately change from subjective payments for subjective loads to objective tariffs for legitimate loads. Under a judicious scheme of fuelwood regulation and pricing, the economic forecasts for coppice woodlots and shelterbelts reported in this Chapter may evoke a much wider interest in agroforestry on the Northern Tablelands. This in turn could contribute towards ecologically sustainable development in the region because multi-species shelterbelts and coppice plantings provide income, create habitat and protect soil, water and livestock. Species and site factors for fuelwood plantations have been identified; establishment and silvicultural procedures are known. The remaining key ingredients are community motivation, government innovation and sympathetic financial institutions.

Chapter 10. Irrigation of a fuelwood plantation with sewage effluent: an Armidale case study

10.1. Introduction

Although the reuse of municipal wastewater for agricultural irrigation is one of the oldest forms of water reclamation (Shuval 1977), land disposal in developed countries has been largely replaced by conventional treatment due to increases in the quantity and intensity of sewage production, changes in sewage composition, particularly in areas of heavy industry, and shortfalls in availability of suitable land (Environment Protection Authority EPA 1983). The conventional means of disposing wastewater in Australia is direct discharge to natural freshwater systems and marine environments (Hart and Lake 1987). This activity has been linked to eutrophication of freshwater systems (Creagh 1992; Polglase *et al.* 1994), destruction of marine reefs and sea-grass beds (Alexandra and Eyre 1993), pollution of groundwater (Leece 1990), and has caused major public health problems in Australia (Manning and Kirkman 1993). As a consequence, water managers are seeking alternative means to dispose of wastewater. Society has increasing regard for effluent as a recyclable natural resource of considerable environmental and economic benefit, instead of a social and economic liability (Borough and Johnson 1990; Manning and Kirkman 1993).

Various alternative measures have been developed for the disposal of municipal wastewater and sludge, including desiccation and incineration, mine rehabilitation, landfill, compost production, industrial cooling, and biological breakdown using artificial wetlands. The most common alternative in Australia, however, is flood irrigation of pastures for sheep and cattle grazing, and irrigation in parks, recreation areas and tree plantations is increasing (Stewart *et al.* 1986). The main objective of effluent irrigation is to maximise effective waste treatment over a minimum land area as rapidly as possible (State Pollution Control Commission SPCC 1979) without causing pollution and long-term degradation of land (EPA 1983). The need for construction of multi-million dollar P and N-treatment facilities can be avoided (Hammill 1993).

The use of tree plantations for land disposal provides a cyclic benefit. Natural hydrological and physiological mechanisms in the soil and vegetation act to purify and disperse wastewater while marketable organic by-products in the form of crops, fodder and trees can be produced. The most efficient application system is spray irrigation (Nutter and Red 1985). Water is expelled by evaporation of effluent from air-borne droplets, vegetative surfaces of trees, pasture and weeds, and litter and soil surface. Nutrients are adsorbed by low nutrient soils, processed by microbial activity in the soil and immobilised by trees and weeds in the form of leaf matter and wood (Hammill 1993). Irrigating trees for production of timber requires less stringent health considerations than irrigation of crops for human consumption, and well planned projects can have important social, aesthetic and environmental benefits (Stewart *et al.* 1986).

An escalating interest in fuelwood plantations irrigated with municipal sewage effluent in Australia (Stewart and Salmon 1986; Stewart *et al.* 1986; Kube *et al.* 1987; Allender 1988; Manning and Kirkman 1993) suggests that pilot investigations be undertaken in wood-burning communities. This chapter aims to describe the silvicultural and engineering requirements of a hypothetical fuelwood plantation irrigated with wastewater in Armidale. Site and species selection criteria and harvesting strategies are outlined with respect to irrigation factors. Hydrology and nutrient factors are used to determine irrigation rates, nutrient loading rates, and the optimum plantation area. Tree growth is estimated from a review of literature and economics are outlined.

10.2. Wastewater treatment in Armidale

Municipal sewage contains a complex mixture of mineral matter (dissolved salts, trace metals), organic matter (carbohydrates, lignins, fats, soaps, detergents, proteins) and living matter (bacteria, viruses, protozoa) originating from discharges of spent water from urban runoff and domestic bathrooms, washing machines, kitchens and lavatories (Bolton and Klein 1971). The treatment of such waste requires a sewerage system and a sewage treatment plant. The sewerage system comprises a network of drains and pipelines (sewers) for transporting effluent from urban zones to the sewage treatment plant. The plant is a facility in which various mechanical, biological, and sometimes chemical procedures are used to dilute and separate the various constituents of domestic wastewater.

Armidale's wastewater treatment facility was built in the late 1930s and augmented in 1975 to cater for over twice its present population of 23 000. It is a conventional 'trickling filter' system with preliminary, primary, secondary and tertiary treatment components. The facility receives an average 5.5 $ML.day^{-1}$, which includes raw sewage and stormwater runoff. Of this, about 5.3 $ML.day^{-1}$ of treated effluent enters Commissioners Waters, and ultimately flows into the Macleay River valley (Figure 10.1). The remainder is either evaporated from the oxidation ponds or applied by flood irrigation to adjoining land to enhance pasture production. The quality of effluent released from the tertiary stage retention ponds (shallow oxidation ponds covering a total area of 9.5 ha) is very high by Australian standards and the area has recently been designated a wildlife reserve. The area is used by migratory Japanese snipe *Gallinago hardwickii.*

Concentration of P in treated effluent released from Armidale's facility was 4.6 $mg.L^{-1}$ in June 1993, nearly 100 times the desired level of P for natural water systems (50 $\mu g.L^{-1}$; Hammill 1993). High P levels promote excessive growth of phytoplankton, filamentous algae and macrophytes (Hammill

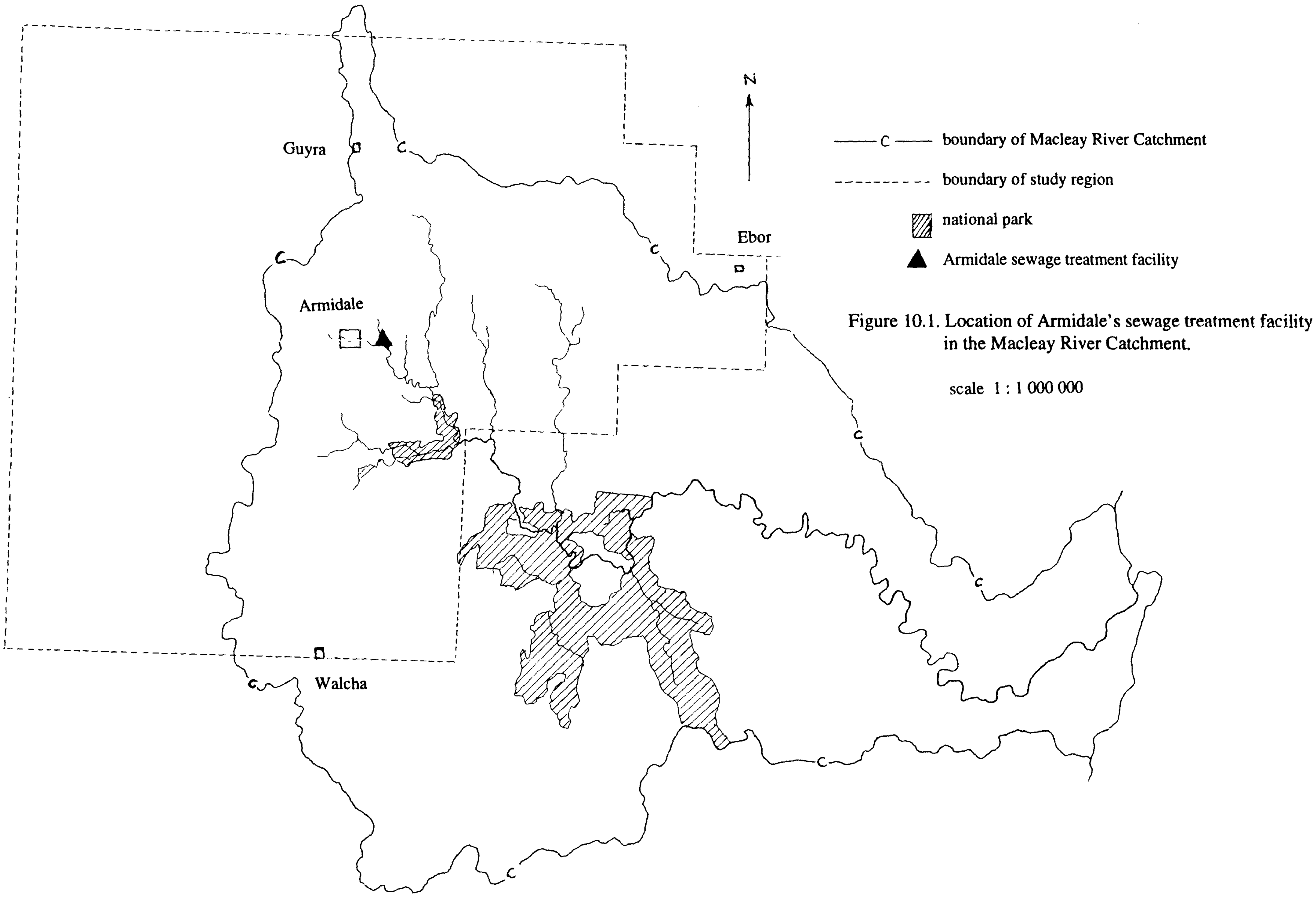

Figure 10.1. Location of Armidale's sewage treatment facility in the Macleay River Catchment.

1993), and phytoplankton communities dominated by green algae can be replaced by those dominated by more toxic blue-green algae (Krebs 1985). Total N concentration (organic N, oxidised N, ammonia) was 21.9 $mg.L^{-1}$ and 5-day BOD (BOD5) was 4.0 $mg.L^{-1}$ in June, 1993.

10.3. Prospects for an effluent irrigated fuelwood plantation in Armidale

10.3.1. Preview

The nutrient-rich wastewater produced at Armidale sewage treatment facility provides an opportunity to develop a rapid growth, short rotation fuelwood production system close to town, augmenting Armidale's fuelwood supply and avoiding possible ecological damage associated with insensitive fuelwood extraction elsewhere. Financial benefits may be realised in terms of marketing firewood and other products such as briquettes or mulch, and the construction of a chemical decontamination facility would be avoided. Other benefits would result, such as improvement of downstream water quality and recreational potential in Commissioners Waters, habitat diversification around the retention ponds, local employment, research and educational opportunities, and promotion of sustainable community forestry in the public interest.

10.3.2. Site selection

Armidale City Council and Dumaresq Shire Council each own approximately 40 ha of cleared land adjacent to the treatment works and retention ponds, and although the potential for major flooding is negligible and erosion potential is low, poor drainage associated with heavy soil would constrain effluent disposal. Subsurface waterlogging could lead to problems such as manganese (Mn^{2+}) toxicity in susceptible plants (Hammill 1993). Severe frost and minimum winter temperatures of -11°C, associated with the land's position in a shallow valley, would retard plantation performance and may result in considerable tree mortality (section 9.2.2). Land within 100 m from a watercourse, or a soil depth of less than 1.5 m, should not normally be used for irrigation (EPA 1983). The ideal characteristics for irrigation are deep, well structured soils on flat to gently sloping land (SPCC 1979; EPA 1983). Soils should allow adequate infiltration and percolation but have sufficient clay and organic matter to retain nutrients and make them available to the vegetation (EPA 1983). Mid to upper slopes and crests are considered best for irrigation. Land adjoining Hillgrove State Forest (sect. 8.4.1) would be suitable.

10.3.3. Species selection

Nutrient removal

In addition to the species selection criteria outlined in section 9.2.1, a species' capacity to remove nutrients and water from the soil is important in selection for effluent removal. Australian timber species strongly dominate plantation irrigation worldwide (Stewart 1988; cited in Manning and Kirkman 1993) and overwhelming evidence supports the benefits of water and nutrient in eucalypt growth and development. Schönau and Herbert (1989) reviewed results of field experiments in the fertiliser treatment of various *Eucalyptus* spp. in several countries, concluding that full exploitation of site productivity at planting time was the main recourse for improving yields.

The higher the proportion of foliage and leaf litter in a plantation, the greater its rate of nutrient accumulation. Stewart *et al.* (1988) found that *Casuarina cunninghamiana* and *E. camaldulensis* accumulated more P, N and potassium (K) than other species due to their relatively large crown and litter masses (25% by weight cf. 8-9% by weight for *E. saligna* and *E. grandis*). Flinn *et al.* (1979) reported work in the USA which showed that *Quercus* spp. (oak) had the capacity to remove large amounts of nutrients, including heavy metals, and Carlson (1992) reported high rates of N uptake in *Populus* spp. (poplar). This benefit may have been negated by the deciduous nature of many exotic hardwoods (i.e. returning nutrients to the ground), although no confirmatory evidence was cited.

Fuelwood quality

A prime consideration in the production of fuelwood from effluent-irrigated plantations is timber density. The rapid growth of hardwood species under effluent irrigation in Dubbo has prompted the forestry industry to describe the wood quality as 'soft' (Hammill 1993) because deposition of cellulose fibres, giving strength and structural quality to the wood, does not occur to the extent of naturally grown trees. Quick-grown, soft quality, low-density wood burns rapidly with fairly low heat production, and is not good firewood (Hammill 1993). Several tests have been conducted to assess the density of trees irrigated with sewage effluent. Five-year *E. camaldulensis* had an oven-dry density of 530 $kg.m^{-3}$ in Alice Springs (Kube *et al.* 1987), considerably less than the 900 $kg.m^{-3}$ reported by Bootle (1983) for naturally occurring *E. camaldulensis*. McKimm (1984) reported low timber densities for 5-year *E. grandis* (~ 520 $kg.m^{-3}$), *E. botryoides* (~ 495 $kg.m^{-3}$) and *C. cunninghamiana* (~ 430 $kg.m^{-3}$) irrigated with sewage. The proportionally greater increment of sapwood associated with fast growth is likely to account for lower wood density.

Growth and yield

There is ample growth and yield evidence in Australia to support the establishment of large-scale sewage plantations. After 4 years growth in Wodonga, Victoria, Stewart *et al.* (1988) found that mean height of *E. grandis*, *E. saligna* and *Populus* spp. ranged between 14.3 and 15.0 m, representing an MAI of 32 $m^3.ha^{-1}.yr^{-1}$. Promising growth was also exhibited by *C. cunninghamiana* and *E. camaldulensis*, with MAIs over 10 $m^3.ha^{-1}.yr^{-1}$. Hammill (1993) observed an average height of about 4.4 m after 15 months in *E. grandis* and various exotics planted in Dubbo, while other species including *E. saligna* and *E. camaldulensis* averaged over 2.5 m. Kube *et al.* (1987) found MAIs for effluent-irrigated *E. camaldulensis* plantations in Alice Springs to range from 7.2 to 19.3 $m^3.ha^{-1}.yr^{-1}$ after 5 years, providing the equivalent of 14.4 to 44 $t.ha^{-1}$ of dry fuelwood. Stewart *et al.* (1986) predicted an MAI of 20 $m^3.ha^{-1}.yr^{-1}$ for an *E. grandis* - *E. camaldulensis* plantation in Loxton, SA, producing the equivalent of 90 $t.ha^{-1}$ of air-dry firewood after 8 years. In another South Australian study, Allender (1988) estimated an MAI of 32 $m^3.ha^{-1}.yr^{-1}$ for *E. grandis* and 13 $m^3.ha^{-1}.yr^{-1}$ for *E. camaldulensis* after 3 years, and concluded that effluent-irrigated plantations could provide sustainable yields of over 20 $m^3.ha^{-1}.yr^{-1}$ of air-dry stem biomass. The author recorded an initial mortality rate of under 1%. Other promising species are *E. botryoides* (Turnbull and Pryor 1984) and *E. globulus* (Stewart and Flinn 1984).

Of the exotic hardwood species, poplar hybrids have demonstrated excellent potential under irrigation. A 30 ha plantation of semi-evergreen poplar clones (*P. deltoides* x *P. nigra*) planted at a stocking density of 404 $stems.ha^{-1}$ in Wangaratta, Victoria, had a mean height of 16 m, a mean DBH of 20 cm, and a mean volume of 67 $m^3.ha^{-1}$ after 4½ years (Stewart *et al.* 1986). The authors expected an MAI of 25 $m^3.ha^{-1}$ over a 15 to 20 year period. After 5 seasons growth in the comparatively cold climate of Vernon (British Columbia, Canada), Carlson (1992) reported a mean height of 13.6 m and mean DBH of 10.6 cm for hybrid *P. deltoides x P. trichocarpa* grown with municipal effluent under spray irrigation, with maximum MAI of about 15 $m^3.ha^{-1}$.

Management considerations

An important consideration in effluent-irrigated plantations is the below ground form of a tree, in particular the root to stem ratio. Borough and Johnson (1990) and Hammill (1993) described the problem of windthrow in irrigated plantations, where abundant water and nutrients (N and P) encouraged rapid foliage and canopy growth but shallow rooting systems. Stewart *et al.* (1988) presented the preliminary findings of a biomass harvesting experiment in Wodonga in which sub-samples of 7 tree species from effluent-irrigated land were destructively sampled after 4 years to determine the weight and nutrient content of foliage, stem and roots. *Populus deltoides* had a relatively high percentage of root biomass consistent with wind stability, making it a desirable species. Trees may be periodically deprived of irrigant to force deeper root development and enhance plant stability.The ability of certain trees to coppice after harvesting plays a large part in selecting species for fuelwood plantations. A major advantage of coppice rotations in sewage irrigated plantations is the increased rate of biomass acquisition in coppice stems and greater utilisation of effluent.

10.4. Hydrologic calculations

10.4.1. Rate of effluent application

Given that all treated water in Armidale is available for irrigation of a fuelwood plantation, the main objective is achievement of maximum effective waste treatment over a minimum land area as rapidly as possible without contaminating the soil (SPCC 1979). Infiltration capacity is the critical design parameter and is dependent on several factors including soil type, slope, crop characteristics and antecedent moisture. CSIRO developed a hydrologic model WATLOAD (reported in Lehane 1992; Hammill 1993) which predicts annual water load requirement (WLR) for a *Pinus radiata* plantation without causing nutrient contamination to soil and water. The relationship is adaptable to any species:

$$WRL = ET - P + I_c + I_f + R + D + \Delta S \quad \text{.......... } 10.1$$

where:
- ET = evaporation
- P = precipitation
- I_c = canopy interception
- I_f = forest floor interception
- R = runoff
- D = deep drainage (percolation) to groundwater
- ΔS = change in soil moisture content

Of the independent variables, ET, I_c, I_f, R and D can be manipulated to maximise WRL. I_f and I_c, in which rainfall is intercepted and evaporated before reaching the soil surface, can be enhanced by irrigating during the day rather than night, and by using sprinkler or drip rather than flood or furrow irrigation. More importantly, ET and I_c can be maximised and R and D minimised by maintaining a high growth rate and large amounts of foliage. Assuming that ΔS under a mature irrigated forest with rapid organic turnover is negligible, and R and D are minimised, then:

$$WLR = \sum_{i=1}^{12} \left(ET - P + I_c + I_f\right)_i \quad \text{.......... } 10.2$$

where i = month

Published crop factors can be used to estimate ($ET + I_c + I_f$). A crop factor of 1.5 (Stewart *et al.* 1988) is used to establish WLR for an Armidale fuelwood plantation (Table 10.1).

Table 10.1. Calculation of the WLR for an irrigated fuelwood plantation in Armidale.

Month	Rain (mm)	Evap (mm)	Deficit (mm)	Est. ET.(mm) [1]
Jan	102.2	173.3	- 71.1	106.65
Feb	86.2	142.5	- 56.3	84.45
Mar	65.8	136.1	- 70.3	105.45
Apr	46.8	99.3	- 52.5	78.75
May	44.2	65.1	- 20.9	31.35
June	57.5	46.8	+ 10.7	0.00
July	49.6	51.2	- 1.6	2.40
Aug	48.7	75.6	- 26.9	40.35
Sept	51.0	106.2	- 55.2	82.80
Oct	67.7	133.0	- 65.3	97.95
Nov	79.7	156.9	- 77.2	115.80
Dec	88.2	185.7	- 97.5	146.25
TOT	787.6	1371.7	-584.1	829.20 = WLR

1. Estimated evapotranspiration = tree crop factor (1.5) * monthly deficit

The average WLR for an Armidale plantation is 830 $mm.yr^{-1}$ or 8.3 $ML.ha^{-1}.yr^{-1}$. This is substantially lower than hydraulic loading rates reported for centres with higher annual water deficits including Dubbo (Hammill 1993), Wodonga (Stewart *et al.* 1988), Alice Springs (Kube *et al.* 1987) and Perth (Manning and Kirkman 1993).

10.4.2. Optimum plantation area

The field area (A) is the area of land (ha) across which irrigation takes place, and is calculated using the relationship (SPCC 1979):

$$A = (36.5*Q)/L \qquad \text{10.3}$$

where Q = wastewater flow rate ($kL.day^{-1}$)
L = WLR ($mm.yr^{-1}$)

The mean rate at which raw sewage enters Armidale's treatment works is 5.5 $ML.day^{-1}$ or a total of 2010 $ML.yr^{-1}$. Because secondary treated water is discharged into a series of tertiary treatment ponds from which it is eventually released into the receiving waters, there is some loss from surface evaporation. Given a total pond area of 9.5 ha and an annual water deficit of 584.1 mm (Table 10.1), mean annual evaporation (MAE) is calculated as 55.5 ML. Thus $Q \cong 1955$ $ML.yr^{-1}$ or 5355 $kL.day^{-1}$. Since WLR = 830 $mm.yr^{-1}$ (Table 10.1), minimum field area (A) is 235.5 ha.

10.4.3. Irrigation scheduling

It is important that the rate of application of irrigation waters based on WLR modelling be irregular. It will be necessary to monitor daily changes associated with rainfall events and evapotranspiration, annual fluxes associated with trends in seasonal climatic conditions (no irrigation will take place in winter), and long-term changes according to age and structure of the plantation to ensure irrigation rate does not exceed the system's capacity to assimilate effluent. To determine the rate at which effluent should be applied in the first year of irrigation, a broad understanding of the hydrology of maturing plantations is required. By calculating monthly water uptake, Borough and Johnson (1990) estimated the irrigation rate for closed canopy pasture and eucalypts to be 4.93 and 12.7 $ML.ha^{-1}.yr^{-1}$, respectively. Assuming the same ratio for Armidale, and given that maximum WLR is 8.3 $ML.ha^{-1}.yr^{-1}$ (section 10.4.1), an initial application rate of 3.25 $ML.ha^{-1}.yr^{-1}$ or 325 $mm.yr^{-1}$ is feasible when the proposed planting site is dominated by pasture (i.e. 8.3 x 4.93/12.7 $ML.ha^{-1}.yr^{-1}$). If canopy closure is assumed after 6 years, by which time annual growth increment will be relatively high and the maximum annual application rate of 8.3 $ML.ha^{-1}.yr^{-1}$ will be achieved, the following WATLOAD output (Figure 10.2) is useful for estimating intermittent irrigation rates.

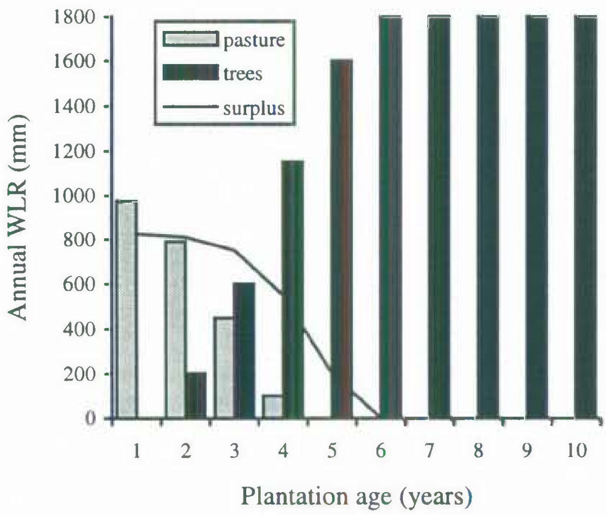

Figure 10.2. Sample WATLOAD output showing relative annual WRL for effluent-irrigated trees and pasture (after Hammill 1993).

Figure 10.2 shows that the requirement for effluent storage (surplus) becomes less as pasture is suppressed by tree growth and canopy closure. Pasture ceases to contribute to WRL after 4 years, and WRL reaches maximum after 5 years. Based on this relationship, the desired rate of irrigation for the first six years of Armidale's proposed plantation is estimated at 3.25, 3.35, 3.70, 4.95, 7.05 and 8.30 $ML.ha^{-1}.yr^{-1}$ in years 1 through 6 respectively.

The long-term method of scheduling from which the above average volumes were derived fails to account for day to day fluctuations. While hot, dry weather affords the opportunity to irrigate at a maximum rate, several days of cool, wet weather can prevent irrigation for weeks. This problem was exemplified by Stewart *et al.* (1988), who found that the rate of irrigation in a plantation in Wodonga varied from 11.9-17.5 $ML.ha^{-1}.yr^{-1}$ (1190-1750 $mm.yr^{-1}$) over 4 years. Hourly application rate is also important. Hammill (1993) suggested that the low application rate adopted in Dubbo (4.2 $mm.hr^{-1}$) permitted water to permeate steadily through the soil over a wide area and discouraged surface root development. Excessive or prolonged irrigation may cause deep seepage, overland flow, ponding or waterlogging. SPCC (1979) listed the maximum hourly rates at which wastewater should be applied under various conditions (Table 10.2).

Table 10.2. Maximum hourly rates for spray irrigation in millimetres (assuming the soil has a vegetative cover and is well drained) (from SPCC 1979).

	Land slope		
Soil type	0-8%	8-12%	12-20%
medium loams, sandy clays over a heavy subsoil	13	10	8
clay loams over a clay subsoil	10	8	5
silt loams and silt clays	8	5	4
clays	5	4	2.5

Assuming the selected site comprises heavy duplex soils with slopes less than 12% then the hydraulic rate of 4.2 $mm.hr^{-1}$ used by Hammill (1993) may be appropriate for Armidale. An irrigation time of 5 hours undertaken during the hottest part of the day (1030-1530 hrs) is suggested, whereby the maximum daily rate is 21 mm, less than the maximum recommended rate of 30 $mm.day^{-1}$ (SPCC 1979). The average return period (R_T) is the time required for the complete dosing cycle and is denoted by (SPCC 1979):

$R_T = (10.A.R.T)/Q$ 10.4

where A = plantation area = 235.5 ha
R = max. application rate = 4.2 $mm.hr^{-1}$
T = irrigation time per day = 5 hrs
Q = wastewater flow rate = 5 355 $kL.day^{-1}$

Average R_T for Armidale is calculated from eq. 10.4 to be 9.24 days (~ 222 hours). This infers that application of effluent to a 235.5 ha plantation (with total canopy closure and vigorous growth) at a rate of 4.2 $mm.hr^{-1}$ over 5 hours (i.e. 21 mm per irrigation event) every 222 hours throughout the year, will utilise the entire volume of sewage effluent generated in a year (1955 ML). This offers a guideline for short-term irrigation scheduling, although it must again be modified to account for seasonal variation. Irrigation should not proceed in the colder months (May to August) due to low water deficits, and irrigation should be maximal during summer when deficits are high. Table 10.3 lists the monthly water deficits (from Table 10.1), average daily irrigation rates for each month (based on calculation of a monthly irrigation index) and return periods for each month.

Table 10.3. Calculation of mean daily irrigation rate (Qm) and return period (R_T) for each month.

Month	Deficit (mm)	MII(%) [1]	Qm ($ML.mth^{-1}$) [2]	Qm ($kL.day^{-1}$)	R_T (days)	R_T (hrs)
Jan	- 71.1	0.130	254	8 190	6.04	145
Feb	- 56.3	0.103	201	7 180	6.89	165
Mar	- 70.3	0.129	252	8 130	6.08	146
Apr	- 52.5	0.096	188	6 270	7.89	189
May	-	-	0	0	-	-
June	-	-	0	0	-	-
July	-	-	0	0	-	-
Aug	-	-	0	0	-	-
Sept	- 55.2	0.101	198	6 600	7.49	180
Oct	- 65.3	0.120	234	7 550	6.55	157
Nov	- 77.2	0.142	278	9 270	5.33	128
Dec	- 97.5	0.179	350	11 290	4.38	105
TOT	- 545.4	1.000	1 945	na	na	na

1. MII (%) = monthly irrigation index = $^{Deficit}/_{\Sigma Deficit}$
2. Qm = MII * Q (where Q = 1 955 $ML.yr^{-1}$).

Irrigation should take place over an eight month period from September to April according to Table 10.3. December will have the highest application volume of 350 ML on account of its relatively high evaporation (December comprises more daylight hours than any other month) and relatively low rainfall.

10.5. Maintenance of site quality

10.5.1. Background

The lands to which wastewater is applied should not degrade over time, groundwater and surface waters should not become contaminated, and community amenity should not be affected by odour, dust, flies or noise (Leece 1990). In short, wastewater use should be ecologically and socially acceptable. Certain conditions are stipulated for effluent quality, testing, data recording and irrigation management in relation to the potential health hazards associated with the reuse of sewage (SPCC 1980; Bouwer and Idelovitch 1987). Potential problems associated with macronutrient, salt and heavy metal accumulation in soils must be addressed in the planning stage.

The quantity of nutrients accumulated by a plantation depends on the nutrient loading rate (supply) and the trees' capacity to absorb the nutrient (demand). A long-term buildup of soil nutrients may cause toxicity to plants where supply exceeds demand, leading to project failure. Periodic cessation of irrigation in conjunction with the establishment of a high nutrient demanding crop (such as maize) can reverse soil nutrient accumulation (Borough and Johnson 1990), or supply and demand can be married by increasing the area of plantation or reducing the rate of hydraulic loading. This is desirable in certain locations such as Alice Springs, where Kube *et al.* (1987) calculated that about 40% of N and K, 10%

of P, Mg and Ca, and less than 5% of Na and Cl were recovered by above-ground biomass of the highest productivity *E. camaldulensis* stand (including trees and pasture), the remainder being immobilised in the soil through cation exchange or leached to groundwater.

There are maximum rates at which forest plantations can absorb nutrients. Borough and Johnson (1990) estimated that plantations can accumulate N and P at rates of 350 and 50 $kg.ha^{-1}.yr^{-1}$, respectively. Stewart *et al.* (1988) provided ranges of 340-530 $kgN.ha^{-1}.yr^{-1}$ and 40-110 $kgP.ha^{-1}.yr^{-1}$. Application of N should not exceed 500 $kg.ha^{-1}.yr^{-1}$ if leaching is to be minimised (EPA 1983) and organic loading rates of 200 kg $BOD.ha^{-1}.wk^{-1}$ should not be exceeded, with lower rates for sandy or clayey soils (SPCC 1979). High levels of suspended solids (SS) can reduce water infiltration and soil aeration, hinder oxygen movement from atmosphere to root zone, and may retard growth or even kill plants (Bouwer and Idelovitch 1987). EPA guidelines state that the treated irrigant in Dubbo should not cause in excess of 60 $mg.L^{-1}$ of non-filtrable residue (Hammill 1993).

Salinisation is a major problem in water renovation. Municipal water contains 200-400 $mg.L^{-1}$ more salt ions (e.g. Na^+, Cl^-, Mg^{2+}, Ca^{2+}, CO_3^{2-}, HCO_3^-) than input water for domestic supply (Bouwer and Idelovitch 1987), and according to chemical analyses of domestic supply and wastewater in Israel, this represents an approximate 50% increase in electrical conductivity (EC) (Noy and Feinmesser 1977). Salinisation of the soil profile may occur if the rate of loading is greater than the plantation's capacity to absorb it or the soil's capacity to leach it away from the root zone. While some salt ions are toxic to plants, and have been implicated in growth impairment through iron deficiencies (Stewart *et al.* 1981) and osmotic effects (EPA 1983), the main effect is soil structure decline and subsequent loss of infiltration capacity as sodium ions adsorb to soil particles (Noy and Feinmesser 1977; Bouwer and Idelovitch 1987). This causes stunted growth and tree mortality and reduces the ability of the site to accept, treat and dispose of waste (EPA 1983).

10.5.2. Nutrient loading

Having established the effluent flow rate and plantation area for Armidale (section 10.4), it is necessary to estimate the loading rate of key effluent-borne nutrients using the following expression (from SPCC 1979):

$$L = \frac{C \cdot Q}{1000 \cdot A} \qquad 10.5$$

where L = loading rate of constituent ($kg.ha^{-1}.day^{-1}$)
C = concentration of constituent ($mg.L^{-1}$) in the wastewater
Q = average daily effluent loading (5355 $kL.day^{-1}$)
A = plantation area (235.5 ha)

Based on the proposed application area of 235.5 ha, Table 10.4 provides a list of the average loading rates for several key nutrients in Armidale wastewater.

Table 10.4. Loading of Armidale wastewater constituents across a proposed 235.5 ha fuelwood plantation

		Nutrient loading rate (L)		
Chemical	Conc. ($mg.L^{-1}$)*	$kg.ha^{-1}.day^{-1}$	$kg.ha^{-1}.yr^{-1}$	$t.yr^{-1}$
BOD5	4.0	0.091	33.20	7.82
SS	19.0	0.432	157.69	37.14
Total P	4.6	0.105	38.18	8.99
Total N	21.9	0.498	181.76	42.81

* July 1993 sampling.

Having established a maximum or 'critical' effluent application rate of 33.6 $mm.wk^{-1}$ in December (derived from Table 10.3), it is also possible to estimate the critical loading rate of key effluent-borne chemicals during this month. Equation 10.5 is adapted by simply replacing Q (5355 $kL.day^{-1}$) with Qm (11 290 $kL.day^{-1}$ for December). Results are shown in Table 10.5.

Table 10.5. Critical loading of Armidale wastewater in December

		Critical loading rate (L) for December		
Chemical	Conc. ($mg.L^{-1}$)*	$kg.ha^{-1}.day^{-1}$	$kg.ha^{-1}$	total kg
BOD5	4.0	0.192	5.94	1 390
SS	19.0	0.911	28.24	6 650
Total P	4.6	0.221	6.84	1 610
Total N	21.9	1.050	32.55	7 660

* from July 1993 sampling.

The maximum BOD5 loading of 1.34 $kg.ha^{-1}.wk^{-1}$ is two orders of magnitude less than the recommended maximum (200 $kg.ha^{-1}.wk^{-1}$; SPCC 1979), the 19 $mg.L^{-1}$ concentration of SS is roughly a third of the suggested maximum (60 $mg.L^{-1}$; Hammill 1993), and the proposed application rate of 181.76 $kgN.ha^{-1}.yr^{-1}$ is less than the EPA standard of 500 $kgN.ha^{-1}.yr^{-1}$ (EPA 1983). While no standard was cited for P application, the proposed 38.18 $kgP.ha^{-1}.yr^{-1}$ is less than the 40-110 $kgP.ha^{-1}.yr^{-1}$ range given by Stewart *et al.* (1988) for plantation uptake. Thus the proposed area is considered large enough to ensure adequate absorption of BOD5, SS, P and N without short to medium-term soil or groundwater contamination. It must be stressed, however, that initial start-up effects of land disposal of wastewater are less important than the steady state conditions which could occur with continuous operations (Hook and Kardos 1978), thus long term monitoring of soil-N is essential. Nutter and Red (1985) stressed that subsurface water quality from forest disposal of effluent in the US must not exceed drinking water standards, of which the N standard of 10 $mg.L^{-1}$ is most critical. Through monitoring of subsurface soil water, this standard could be used as an indicator of overall effectiveness of the Armidale plantation system.

Potential problems associated with increasing salinity and alkalinity (pH) should be addressed through soil sampling and modification of hydraulic loading rates. While foliar analysis for Cl^- and Mg^{2+} provided no evidence of salt accumulation in Alice Springs plantings after 5 years, Kube *et al.* (1987) found appreciable salt accumulation in the soil, suggesting the inevitability of long-term problems if application rates were not reduced. A soluble solution of calcium salt such as $CaSO_4$ (gypsum) may be applied directly to soil or diluted with irrigant to reduce salt accumulation (Noy and Feinmesser 1977). Irrigated wastewater must have a pH in the range 6.5 to 8.5 (Armidale's wastewater has a pH of 7.9 according to the June 1993 analysis) and soil pH should be monitored. Soil alkalinity in Alice Springs began to increase after 4 years, and development of sodic horizons were likely in the absence of ameliorative treatments (Sandell 1987). Stewart *et al.* (1988) observed soil pH to increase by 1.0 over a 4 year period in Wodonga. The authors suggested enhancing the uptake of trace elements such as copper, iron and manganese, and maintaining a good litter layer through retention of harvest residue.

10.5.3. Pathogens

Untreated sewage carries a large array of pathogenic bacteria, viruses, protozoa and helminths, and agents for enteric diseases such as dysentery, cholera, typhoid, *Salmonella* gastroenteritis, tapeworm infections, shistosomiasis and ascariasis have often been detected in wastewater (Shuval 1977). Bacterial concentration in treated effluent is determined by the number of faecal coliforms, indicating the extent of faecal contamination and the possible presence of pathogenic bacteria such as salmonella, shigella and cholera (Bouwer and Idelovitch 1987). While this is useful in assessing the feasibility of various end-uses for wastewater, it does not provide clear assurance that wastewater is free from potentially infectious enteric viruses, including poliovirus and hepatitis, which are more resistant to sewage treatment processes (Shuval 1977). This problem is of particular concern in proposals to irrigate crops for human consumption.

Controlled public access to the irrigated 'fuelwoodlot' should be permitted for reasons of community involvement and teaching and research, yet two forms of potential health risk must be addressed. First there is a risk of direct contamination via physical contact with wastewater. This is controlled by denying access during irrigation and until the area is dry (SPCC 1980). Second, there is a risk to workers and visitors of air-borne pathogenic contamination from inhalation of infected spray from sprinkler irrigation. Between 0.1 and 1.0% of sewage sprayed into the air forms aerosols (Shuval 1977) which are capable of transporting micro-organisms some distance (Bouwer and Idelovitch 1987). Bouwer and Idelovitch (1987) refer to a report by the Arizona Department of Health Services which recommend that faecal coliforms not exceed 1000 counts.100mL^{-1} for landscape areas with restricted access. The use of flood irrigation could be explored to counter aerosol transmission of pathogenic organisms.

10.6. Plantation silviculture

10.6.1. Why harvest?

The advantage of harvesting effluent-irrigated plantations is two-fold. First, all plants have a limited capacity to absorb nutrients during surplus conditions, therefore, to maximise the nutrient loading rate, biomass must periodically be removed from the site by harvesting foliage and wood (Hammill 1993) and possibly by grazing and replacing stock (Borough and Johnson 1990). Extractive operations involving whole-tree harvesting, in which timber, bark and foliage are removed from the site, are optimal for effluent treatment, leading to a more rapid decrease in nutrient capital (Schönau and Herbert 1989). This is supported by Wise and Pitman (1981), who found that harvesting the total tree from short-rotation plantations, as compared to the main stem only, resulted in an increase of 50-60% in removal of P and N. Second, the main stem can be used for sawlogs, poles, fencing material and firewood, most branches and bark can be used for firewood, while leaf matter can be either compacted and dried into readily combustible briquettes or shredded and mulched for gardens.

Eucalypts have been found to be the most effective producers of woody biomass in irrigated plantations managed on a short rotation (Stewart *et al.* 1988) and a common rotation time for eucalypt fuelwood plantations overseas is 10 years (Stewart and Salmon 1986). Short rotation forestry has also been shown to be beneficial in terms of nutrient removal. Schönau and Herbert (1989) cited several studies which report that shortening the harvest rotation leads to removal of relatively more sapwood, comprising higher nutrient content than heartwood. Crane *et al.* (1980; cited in Wise and Pitman 1981) suggested that removal of P under 10-year rotations of *E. delegatensis* could be four times greater than under 60-year rotations.

10.6.2. Rotation

Selection of rotation for fuelwood production *per se* is a trade-off between a short-rotation to produce a suitable diameter, and a longer rotation to maximise yield (Stewart *et al.* 1986). Armidale has a relatively cold climate and shorter growing season than centres reported in other projects, yet well chosen sites can produce 20 $m^3.ha^{-1}.yr^{-1}$ from unirrigated shelterbelts (Chapter 7). Assuming a mean MAI of 20 $m^3.ha^{-1}.yr^{-1}$ for effluent-irrigated eucalypts and a post-thinning stocking density of about 1650 stems.ha^{-1} (3 x 2 m), a 20-year rotation is likely to yield trees with a DBH range of 20-40 cm, ideal for fuelwood harvesting and handling. It is thus suggested that fuelwood harvesting from Armidale's wastewater plantation be undertaken on a 20-year rotation.

10.6.3. Clearfell vs. group selection

There are two main silvicultural options. The entire plantation (235.5 ha) could be clearfelled after 20 years, producing about 94 200 m^3 fuelwood at year 20 (assuming MAI = 20 $m^3.ha^{-1}.yr^{-1}$) and meeting Armidale's annual consumption for the following three years, after which effluent-irrigated fuelwood would not be available again until maturation of the first coppice rotation 20 years later. The alternative is partial clearing or group selection, in which a single coupe or portion of the plantation is clearfelled each year. The theory of coupe rotation is simple. For a given rotation *n* years (in this case 20), *n* coupes, each comprising an area of *A*/*n* ha (where *A* is the total plantation area, in this case 235.5 ha), are delineated during plantation establishment. Harvesting commences after about *n*/2 years (10), at a rate of 1 $coupe.yr^{-1}$, and continues for *n* years until harvesting of all 1st rotation coupes is complete (after 30 years). Harvesting of 2nd rotation coupes (in the same order) continues the following year for the next *n* years, and so on.

The volume of fuelwood generated by coupe rotation and clearfelling are similar, but the temporal distribution of production is different. There are some distinct advantages with the coupe system. A maximum 5% of the plantation area (1 coupe or 11.8 ha) is clear at any time under a 20 year rotation using 20 coupes, avoiding ecological disruption associated with a single clearfell operation. Smaller fuelwood volumes (2360 - 7080 m^3) are more easily managed. Fuelwood must be felled, cut, split and stacked for drying *in situ* before being loaded, trucked, and delivered for sale. Preparation of a single 94 200 m^3 volume every 20 years is riskier than smaller annual volumes.

Another benefit of coupe harvesting is the maintenance of a maximum rate of effluent application. Major disruption of the irrigation schedule is unavoidable if the single harvest option is adopted. There is greater opportunity to test the growth performance of different species within different areas of the plantation using a coupe rotation system. Perhaps most importantly, the coupe system is amenable to the generation of income every year after about 12 years, reducing financial risk, and affording greater opportunity for annual reinvestment into the project if the need arises.

10.7. Economic outline

The capital costs associated with effluent-irrigated tree crops include purchase of land and irrigation infrastructure (transmission and storage facilities and distribution, recovery and monitoring system), plantation establishment and maintenance, and employment. An assessment of the direct costs associated with effluent irrigation can be inferred from the 20 ha Bunglegumbie Woods project, in which Hammill (1993) reported a total cost of \$350,000, including \$244,000 for sprinkler irrigation equipment and construction, \$18,500 for seed purchase and propagation, \$31,000 for planting, \$15,500 for initial soil preparation, and $41,000 for maintenance, contract supervision and miscellaneous items (Hammill 1993). It follows that a sprinkle-irrigated plantation of 235 ha is likely to cost well in excess of $4 M.

The respective returns are illustrated using an economic feasibility study undertaken by Stewart and Salmon (1986), in which firewood stumpage was valued at $\$2.60.m^{-3}$. This yielded a return of $\$520\ ha^{-1}$ after 10 years, a value less than that gained from grazing sheep over the same period. Kube (1987) also demonstrated that irrigated plantations could not produce fuelwood profitably at a royalty of $\$5\ t^{-1}$ in Alice Springs. It should be noted that despite these shortfalls, circumstances may arise in which the deficit is less than the perceived cost of treating effluent to a standard at which P and N discharge to a river is permitted (Stewart and Salmon 1986; Borough and Johnson 1990). Armidale's treatment facility faces the prospect of upgrading its treatment works to facilitate the dilution P and N to acceptable concentrations. Based on estimates for tertiary denitrification and P removal in west Dubbo (Hammill 1993), this will require a capital outlay of $13M and annual expenditure of about $220,000; the prospect for a $4M investment in land disposal is considerably more attractive.

If the value-adding process in fuelwood production was undertaken by the City Council, a gross $50,000 to $200,000 (depending on project age) could be generated annually within 10 years of establishment. Intangible benefits would include improved water quality in Commissioners Waters and the Macleay River catchment, increased recreational opportunities in Oxley Wild Rivers National Park, on-site enhancement of wildlife values, creation of educational and scientific opportunities, and development of a 'rural prototype' in fuelwood production and effluent reduction.

Other products could be grown in conjunction with fuelwood, such as fuel briquettes, eucalyptus oil and fencing timber. Kube *et al.* (1987) found that 45% of potential energy was apportioned to the foliage and small branches of young *E. camaldulensis* plantings in central Australia, and Allender (1988) estimated 36% for the same species and 23% for *E. grandis* in South Australia. Assuming that 40% of energy is available in the small branches and foliage of plantation trees in Armidale, approximately 1200 t of non-fuelwood biomass would be generated each year. Innovations such as the 'Comprima' could be used to produce fuel briquettes from leaves, twigs and small branches, suitable for combustion in woodstoves and open fires (Allender 1988). Marketed and sold at about $\$60\ t^{-1}$, briquettes could provide an additional $\$70{,}000\ yr^{-1}$ to the operation. The economic feasibility of producing briquettes from dried foliage should be explored further. The potential for producing fencing timber using effluent-irrigated eucalypt plantations is promising. McKimm (1984) tested various timber properties for fast growth 5-year plantations of *C. cunninghamiana*, *E. grandis* and *E. botryoides* in Mildura, Victoria. While casuarina exhibited severe splitting of post sections during drying and was disregarded as a marketable proposition, visible degrade in eucalypt posts was minor, and measurements of maximum load and modulus of rupture showed that strength properties were sufficient for production of desirable fence posts. Further, the species had grown in 5 years to a size sufficient to yield 3 round posts from each tree, with lengths of 2 m and small end diameters ranging from 7 to 13 cm (McKimm 1984).

10.8. Conclusions

Armidale releases an average of 5.5 ML of treated sewage into the Macleay catchment each day. It contains high levels of the macronutrients P and N. Construction of a chemical decontamination plant to ameliorate P and N could be well over $10M. An alternative, biological approach comprises a $4M land disposal system using fuelwood trees. It offers an opportunity to increase fuelwood supply in Armidale by 5% after 10 years and 20% after 30 years, and could be managed by Armidale City Council to generate income and jobs. Considering the potential for a significant increase in the price of firewood before the year 2000, the treated plantation option should be explored in full.