

Chapter One: Setting the Scene

Nico Marcar

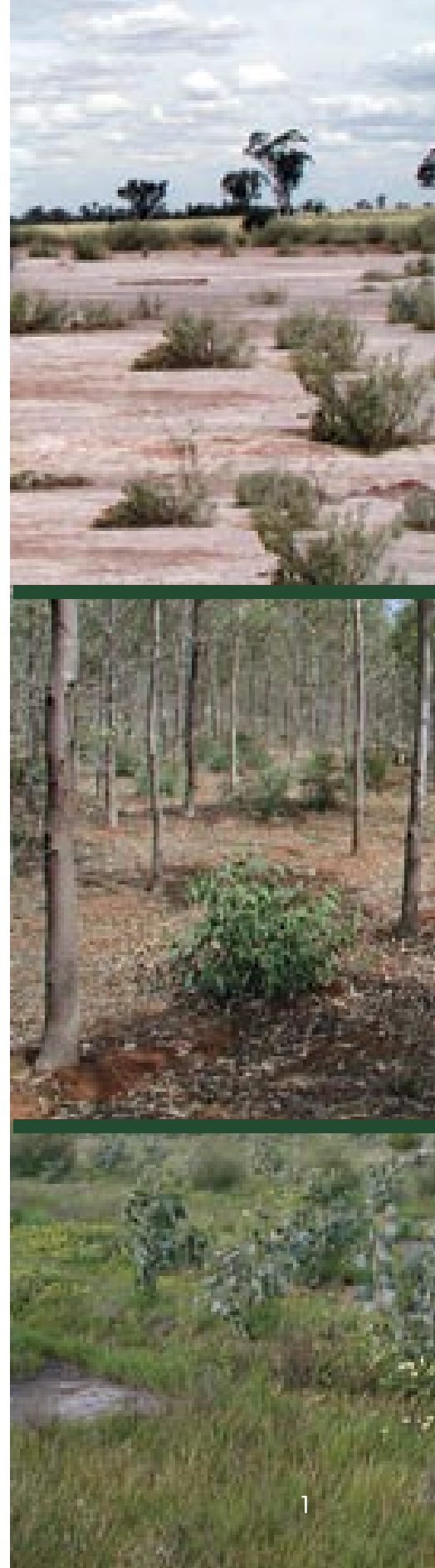
This chapter provides a brief overview of the salinity issues in Australia, vegetation management options for recharge and discharge areas and more specific information related to saline soil classification, responses of trees to salinity and related stress factors and tree growing options for salt-affected environments.

1.1 Australia-Wide Perspective

About a third of Australia (some 29 million ha), including arid and semi-arid regions with saline subsoils, is affected by naturally-occurring salinity. In addition, over 4 million ha of secondary or human-induced saline soils have developed, predominantly in southern Australia (Williamson 1990). There are three types of secondary salinity. The first type, described as scald, is found in low-rainfall pastoral zones and results from grazing-induced soil erosion exposing saline or sodic subsoil. The other two types, in which groundwater is a key component, are usually described as either dryland (saline seepage) or irrigation salinity. Further useful information about classification of salt-affected land can be found in Williams and Bullock (1989) and Semple and Williams (2002).

Dryland salinity generally results from the build-up of salts in surface soil, usually as a result of a rising watertable and subsequent groundwater seepage. These salts have often been stored to depths of 30 m or more in many soil types and have accumulated there from several sources: the ocean via rainfall and as windblown salt, weathering of soil and rock minerals, marine deposition in earlier geological periods and leached solution from upslope areas. Watertables have risen in response to clearing of deep-rooted native vegetation, especially trees (Fig. 1.1). This clearing has allowed large volumes of rainfall to leak through the soil and enter or 'recharge' the groundwater system. This water re-surfaces in 'discharge' areas; rising water brings dissolved salts into the surface zones. Seepage occurs in discharge zones; a range of salinities (from slight to extreme) and soil water regimes (from relatively dry to seasonally waterlogged) is experienced in these zones.

Dryland salinity affects over 2.5 million ha (Table 1.1) and is expanding at a rate of 3–5% a year. The prognosis is for a considerable worsening of salinity and waterlogging problems (to reach 12–15 million ha at equilibrium; or as high as 17 million —Table 1.1), particularly in southern Australia, because groundwater levels continue to rise



and only small-scale land management programs have been implemented so far. Predictions (Fig. 1.2) are based on groundwater trends, field surveys and landscape characteristics. The spread of dryland salinity is based on estimates of areas expected to develop shallow watertables in the next 30–50 years; but their propensity to become saline depends on the amount of salt stored in associated soils. Data on areas affected by different degrees of salinity and shallow watertables are available for specific regions but are not readily available on a state-wide basis. Little information is available on areas that will become differentially saline and wet in future saline landscapes. Many saline soils suffer from periodic or seasonal waterlogging and some may have poor structure. In addition, a significant proportion of Australia’s surface and groundwaters are saline. Over 500 000 ha of irrigated land in Australia are currently affected to some degree by salinity and/or high watertables.

Table 1.1 Area of land affected and potentially at risk by dryland salinity in Australia

State	Area of dryland salinity in 1996 (ha) ^a	Area with high potential to develop dryland salinity 1998/2000 (ha) ^b	Area with high potential to develop dryland salinity 2050 (ha) ^b
Western Australia (WA)	1 804 000	4 363 000	8 800 000
South Australia (SA)	402 000	390 000	600 000
Victoria (Vic)	120 000	670 000	3 110 000
New South Wales (NSW)	120 000	181 000	5 000 000
Tasmania (Tas)	20 000	54 000	90 000
Queensland (Qld)	10 000	NA	3 100 000
Northern Territory (NT)	minor	minor	NA
Total	2 476 000	5 658 000	17 000 000

^a Hayes (1997); ^b Anon. (2000a)

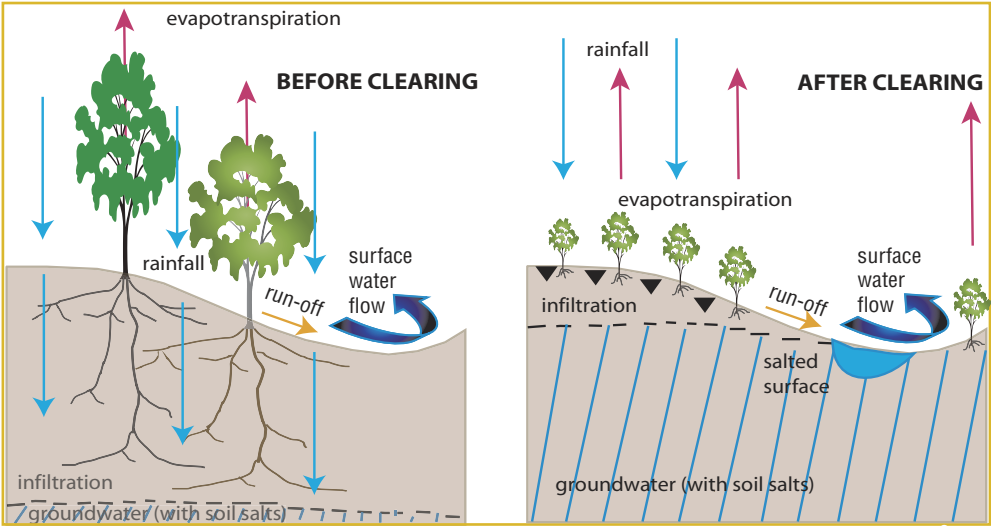
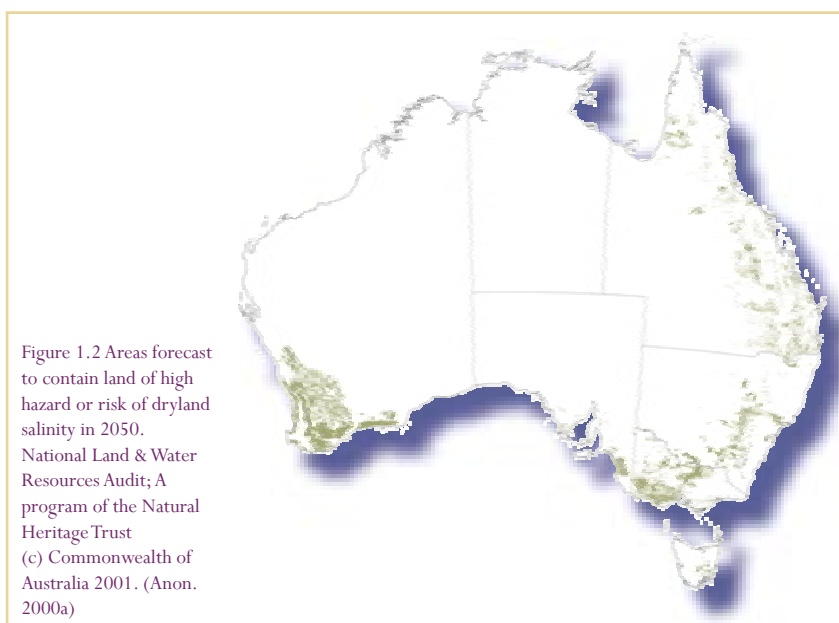


Figure 1.1 Dryland salinity development resulting from watertable rise. (Anon. 1989) (Graphics: RIRDC Publications Unit)

Salinity has both on-site (e.g. decreased land productivity and reduced biodiversity) and off-site impacts. The most significant off-site impact is the salinisation of rivers and other waterways. This affects the supply and quality of water available for drinking, irrigation and industrial use, with serious economic, social and environmental consequences for rural and urban communities. Controlling stream salinisation is a major management consideration for the Murray-Darling Basin (MDB) and other regions in Australia. The ecological values of wetlands, rivers and their associated habitats are also affected. Economic values for on-site (e.g. loss of farm production) and off-site (e.g. water quality, roads, buildings) impacts of dryland salinity are being evaluated (e.g. Beal 1993; Oliver *et al.* 1996). Environmental impacts of salinity include loss of biodiversity and its vital function in keeping landscapes healthy and productive; for example, on mostly private land in the wheat-belt of south-western Australia, a region internationally recognised for diversity and species uniqueness, recent estimates put some 450 species of vascular plants at risk of extinction (Keighery *et al.* 2000; Dillon and Lewis 2001). Non-agricultural impacts of salinity are currently as economically important as agricultural impacts and are predicted to increase.

Salinity can also be 'transient'. Transient salinity is not associated with a permanent saline watertable, but occurs when the upper soil horizons are sodic (section 1.4.3), severely restricting the downward movement of water, leading to the formation of a perched watertable (Rengasamy 2002).



1.2 Vegetation Options for Managing Salinity

Trees have many positive attributes for effective watertable control. They are relatively deep rooted and can therefore reduce leakage, they may use water all year around whenever it is available, and intercept a significant fraction of rainfall before it reaches the soil. Trees with high water consumption are generally the trees that grow well, although species differences in water use are important. Since the main determinants of tree water use are (i) sapwood area, (ii) leaf area and (iii) rooting depth and spread, it is important to use the right tree and silvicultural techniques to promote the best growth possible.

1.2.1 Dryland areas

Dryland salinity can be managed using a combination of revegetation and engineering methods (e.g. Brouwer 2001). Plant-based management, however, allows more cost-effective, productive and large-scale options to be implemented for reducing deep percolation of rainfall in agricultural landscapes. These options include increased use of perennial pastures, agroforestry, crop rotations and management of remnant native vegetation in key 'recharge' (water intake) areas (see for example Walker *et al.* 1999 with respect to MDB), as well as pastures and tree planting in 'discharge' areas. Both local property, catchment and groundwater flow (Coram *et al.* 2000 http://audit.ea.gov.au/ANRA/land/docs/national/Salinity_GFS_Report/REPORT/REPORT.HTM) issues need consideration. Tree planting in discharge areas is likely to be a more effective contribution to managing land and stream salinisation in local (1-5 km² scale) groundwater flow catchments, especially those with high discharge capacity, rather than in intermediate and regional flow system catchments (Hatton *et al.* 2002). To have an effect on recharge in a local and intermediate groundwater flow system requires either strategic planting in target recharge areas or broadscale catchment planting. The scale of the groundwater flow system in an intermediate system means that planting on discharge zones is often ineffective in watertable control. Regional systems occur on a scale that is so large as to make farm based catchment management options impractical. Grass and herbaceous pastures as well as halophytic shrubs have been widely used for saltland management as well (see, for example, Barrett-Lennard and Malcolm 1995; Barrett-Lennard *et al.* 2003). In some dryland sites, watertables in discharge areas may also be lowered using windmill or diesel pumping and by subsurface drainage.

Strategic tree planting (as agroforestry and farm forestry) in both recharge and discharge areas can contribute significantly to controlling rising watertables because of increased use of water in the landscape by reducing recharge and enhanced use of groundwater; some options are shown in Figure 1.3. It is important to recognise that in some landscape types (e.g. parts of the wheatbelt in WA) the rate of groundwater rise is quite rapid with the consequence that so-called 'recharge' areas may soon become increasingly saline and 'discharge'. In many cases, for example on the slopes of the Great Dividing Range in Victoria and New South Wales, tree planting is best targeted to prime recharge areas in order to intercept and use as much water as possible before it enters the groundwater system. The best locations for tree planting to control recharge on individual properties are catchment-specific and require careful discussion and assessment with local specialists and advisers. Recharge control is likely to be a long-term proposition. Opportunities for agroforestry plantings to intercept sub-surface lateral water flows in soil horizons and in 'break of slope' positions (Photo 1.1; Fig. 1.3) are discussed in Silberstein *et al.* (2002). In these landscape positions, there are good opportunities for trees to use water that would otherwise become recharge, for improved growth rates. Several programs are currently underway to involve farming communities in strategic catchment planning for managing both dryland salinity and other important environmental issues. Two examples are the 'Heartlands Initiative' in the southern Murray-Darling Basin (<http://www.clw.csiro.au/heartlands>; Cresswell *et al.* 2002; Myers 2002) and the 'Tools to Achieve landscape Redesign Giving Environmental economic Targets (TARGET)' project in central west NSW (Lynch 2002). Computer simulation programs to assist land managers and researchers in planning strategic

locations for vegetation planting and retention are being developed and tested by CSIRO, state agencies and others. Some of these models are complex whilst others are less so (Williams *et al.* 1997). Some models are being used by state and national agencies to determine the effect of tree planting on landscape water use and off-site impacts. These models differ in how they use groundwater information and whether they incorporate surface flows of water and salts as well as base groundwater flows to rivers.

Most dryland salinity is found in the wheat growing/sheep grazing zones of Western Australia, South Australia, Victoria and New South Wales, with substantial areas also predicted for Queensland (Fig. 1.2). Rainfall limitations of these regions will reduce the range of tree species suitable for planting. In these regions trees are currently grown for firewood and on-farm timber. Other options, such as development of mallee eucalypt plantations for industrial and pharmaceutical oil production in the wheat belt of Western Australia (Bartle 1994) and commercial timber production (JVAP 2000) are underway. Up to 100 000 ha of land in the medium to high-rainfall (600–900 mm) zone in Western Australia, Victoria, South Australia, New South Wales, Queensland and Tasmania are also variably salt-affected and present opportunities for tree growing. These regions (as well as irrigated land) could, in principle, support pulp and/or timber production.

Revegetation using agroforestry in discharge areas (Photo 1.2) also has the potential to reduce salt loads to streams, especially during periods of high salinity ‘spikes’, by reducing the volume of saline subsurface flows as well as run-off. Impacts on stream salinity will be greatest where local groundwater flow systems predominate and, where both recharge and discharge

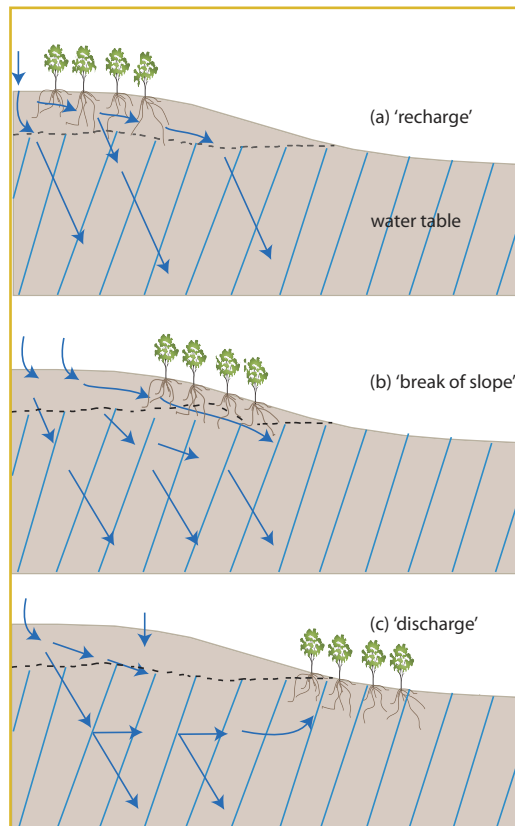


Figure 1.3 Options for location of tree planting for dryland salinity management (Graphics: RIRDC Publications Unit)

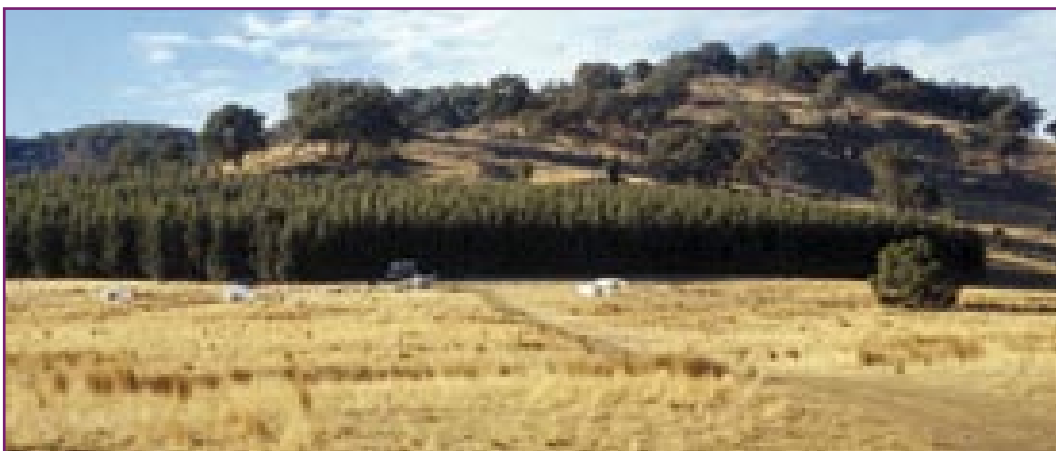


Photo 1.1 Break of slope planting in north east Victoria (Photograph Nico Marcar)

control measures are implemented. There is considerable interest by governments and communities to implement a salinity 'credits' scheme that could be used by catchment management authorities for reducing river salinity (e.g. Murtough *et al.* 2002). The idea is that water removed by trees contributes to salinity management by reducing recharge to groundwater. If impacts on recharge and stream salinity can be accurately predicted, at a range of scales (e.g. property and sub catchment) there is an opportunity to calculate a financial value for targeted revegetation. This potential could, in principle, be realised by tree plantings in discharge as well as in recharge areas. Considerably more effort is required to identify key areas for revegetation under any effective salinity credits trading scheme and this is a focus of current research and policy development.

1.2.2 Irrigation areas

Irrigation salinity may develop in situations where too much water is applied to crops and pastures with the subsequent rise in watertables and there is insufficient drainage to remove accumulated salts. Irrigation salinity is often associated with shallow watertables (since salts can be transported to surface layers by evaporation) and occurs along the Murray-Darling River system in South Australia, Victoria and New South Wales, as well as in small areas in Queensland. Problems are compounded where saline water is applied as irrigation. Close to one million hectares are underlain by shallow groundwater and require drainage to avoid further salinisation (Anon 1999a).

In combination with engineering options, there is scope for planted trees to utilise groundwater (*in situ* or pumped) or the drainage water from other irrigated crops. For example, feasibility studies have been conducted in the Shepparton region of

Victoria for the incorporation of trees into biological systems for concentrating saline water for later disposal (Heath and Heuperman 1994; Heuperman 1999). For soils of low to moderate salinity and where irrigation is managed sustainably, viable wood and/or pulp-producing enterprises may be feasible. Suggested species could include river red gum (*Eucalyptus camaldulensis*), river oak (*Casuarina cunninghamiana*), hybrids between *E. camaldulensis* and *E. globulus* or *E. grandis*, and possibly Tasmanian blue gum (*E. globulus* subsp. *globulus*) and flooded gum (*E. grandis*); of course these species can also be used in dryland saline environments. On soils of



Photo 1.2 Tree planting on saline discharge site in central New South Wales (Photograph Stephen Midgley)

moderate to high salinity, highly salt-tolerant species that may have fodder, firewood and/or on-farm timber uses in addition to other wood values may be considered.

The recently completed Trees for Profit Program (<http://www.forestresearch.vic.gov.au/projects/trees.html>) has generated considerable interest over the last 10 years in planting commercial tree species for agroforestry, salinity control and plantations irrigated with saline water in areas of northern Victoria and southern New South Wales. Pest and disease problems will need to be contained by careful management or use of resistant species.

1.3 Saline Soil Classification

Soil conditions for plant growth deteriorate as salts build up in the soil and/or the duration of waterlogging increases.

Soil salinity is one of the most spatially and temporally variable properties of soils. It is best described in terms of the **electrical conductivity** (EC) with appropriate units (Table 1.2). The most appropriate measure from the plant's perspective (i.e. what its roots are sensing) is to determine the EC of the soil solution, but this is not practical. The next-best measure, but a tedious procedure, is the EC of the extract of a saturated soil paste (EC_e). An alternative (and easier to determine) measure is the EC of a 1:5 soil:water extract ($EC_{1:5}$) — one part by weight (g) of air-dried soil to five parts by volume (ml) of distilled water, which is shaken for one hour then allowed to settle. $EC_{1:5}$ can be converted to EC_e by applying conversion factors (Table 1.3 provides an example, although modifications of these are also used (e.g. by House *et al.* 1998; Bird 2000)). For both methods, soil samples are collected from the field, preferably from the top (10–20 cm) and sub (50–70 cm) soil. The salinity level of surface water and groundwater can also be conveniently measured with a portable conductivity meter.

The electromagnetic (EM) induction technique can be a useful means of assessing salinity over the proposed planting site as well as in the plant root zone (up to 1.5 m in depth). The EM device that has been widely adopted for both purposes is the EM38 (Photo 1.3; Bennett and George 1995; Fogarty *et al.* 1993). It operates by calculating the ratio of an induced electromagnetic field to that of the reflected electromagnetic field. An apparent conductivity (EC_a) is derived and this can be converted to $EC_{1:5}$ and EC_e (Slavich and Petterson 1990). The EM38 is sensitive to the presence of clay and soil moisture conditions. Calibration of EM38 readings is critical for comparisons among sites.



Photo 1.3 Measuring soil salinity with the EM38. (Photograph Stephen Midgley)

Table 1.2 Conversion between salinity units

1 deciSiemen/metre (dS/m)	=	1000 microSiemens/centimetre (μ S/cm)	=	1 milliSiemen/centimetre (mS/cm)	=	100 milliSiemens/metre (mS/m)	=	about 640 parts per million (ppm)
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Commonly, the unit of deciSiemens/metre (dS/m) is used for soil salinity classification. However, milliSiemens/metre (mS/m) is often used in WA. The units of microSiemens/centimetre (μ S/cm) are commonly used for water quality and denoted as EC units. For example, in specifying river water salinity targets in the Murray-Darling Basin, the target for the River Murray at Morgan (SA) is set at about 800 EC units.

Table 1.3 Factors for converting $EC_{1:5}$ to EC_e . Source: Slavich and Petterson (1993); Taylor (1993); Bird (2000).

Group	Soil texture field test	Factor
Sand	Very little or no coherence and cannot be rolled into a stable ball; individual sand grains adhere to fingers.	17
Loamy sand	Slight coherence but cannot be moulded.	14
Sandy loam	Some coherence and can be rolled into a stable ball but not to a thread. Sand grains can be felt during manipulation.	12
Loam	Can be rolled into a thick thread, but will break up before it is 3–4 mm thick; the soil ball is easy to manipulate and has a smooth spongy feel with no obvious sandiness.	10
Clay loam	Can be easily rolled into a thread 3–4 mm thick but will have a number of fractures along its length; the soil is becoming plastic, capable of being moulded into a stable shape.	9
Light clay	Can be rolled to a thread 3–4 mm thick without fracture; plastic behaviour evident, smooth feel with some resistance to rolling out.	8.5
Light medium clay	Plastic and smooth to the touch and will form a ribbon of 7 cm.	8
Medium clay	Handles like plasticine, forms rods without fracture, has some resistance to ribboning shear, forms ribbons to 7.5 cm or more.	7
Heavy clay	Can be rolled to a thread 3–4 mm thick and formed into a ring in the palm of the hand without fracture. Smooth and very plastic with a moderate to strong resistance to rolling out.	6

In this book we use the following classification: saline soils as non-saline ($EC_e < 2$ dS/m), slight (EC_e 2–4 dS/m), moderate (EC_e 4–8 dS/m), high (EC_e 8–16 dS/m) and extreme ($EC_e > 16$ dS/m). These classes refer to average conditions in the root-zone of trees (typically 0.5 m to several metres) and not just the very surface soil.

A number of salinity classes, based on EC values, are commonly recognised. In this book we use the following classification: saline soils as **non-saline** ($EC_e < 2$ dS/m), **slight** (EC_e 2–4 dS/m), **moderate** (EC_e 4–8 dS/m), **high** (EC_e 8–16 dS/m) and **extreme** ($EC_e > 16$ dS/m). These classes refer to **average conditions in the root-zone** of trees (typically 0.5 m to several metres) and not just the very surface soil. Seasonal fluctuations in salinity within the soil profile can be expected. In dryland discharge locations in southern Australia, surface salinities are often much higher than those of the subsoil in summer months due to high evaporation and low rainfall, whilst they will be lower in winter periods due to dilution and leaching from rainfall and lower evaporation rates. The picture can be very different on irrigated land, where subsoils are often saltier.

It is important to note that whilst EC can give an approximation of salt concentration, it does not give any information on salt composition. A broad range of dissolved salts is known to occur in soil and water. In most of Australian cases, sodium chloride (NaCl) is the principal form. However, other ions such as magnesium (Mg), sulphate (SO_4) and bicarbonate (HCO_3) may occur in significant amounts. This leads to the development of alkaline saline soils (high pH, presence of sodium carbonate, high EC), acid sulphate saline soils (low pH, presence of sulphur, high EC) and potential acid sulphate saline soils (high pH, presence of sulphur and high EC) (Fitzpatrick *et al.* 2000). Responses to sulphate-dominant soils are less well characterised for Australian species, but there is some suggestion that they are less harmful for growth than chloride salts (e.g. Grattan *et al.* 1997 in Lambert and Turner 2000).

Soil sodicity is usually expressed as the concentration of exchangeable sodium (Na) relative to the total quantity of exchangeable cations (cation exchange capacity) or the *exchangeable sodium percentage* (ESP). Three sodicity classes are commonly recognised; **non-sodic** (ESP <6%), **sodic** (ESP 6–14%) and **strongly sodic** (ESP >14%). The degree of sodicity can also be assessed in the field by testing for the degree of cloudiness (turbidity, dispersion) when a soil sample is mixed with rain water in a 1:5 ratio. Sodic soils are normally highly to severely alkaline because of the excess Na, HCO_3 and carbonate (CO_3) in soil solution. Sodic soils can also be formed directly from the weathering of certain parent materials thousands of years ago; this possibility increases with increasing siliceous character of the parent material. However, in many cases, sodic soils ('secondary saline soils') are believed to have been formed by leaching of saline soils with fresh water, leaving some of the Na behind. In most cases the dominant associated anion is chloride (Cl). However, in some landforms (e.g. Adelaide Hills, western Victoria), the dominant anion is sulphate; when saline, sulphate-rich groundwater discharges, sulphate salts build up in the soil surface and the soils can become 'potential acid sulphate soils' (Fitzpatrick *et al.* 2000). When drained these soils are likely to become highly acidic, unstable, waterlogged and infertile, and therefore difficult to rehabilitate.

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Soil pH is important for plant growth since it governs the availability of essential plant nutrients and how nutrients react with each other (e.g. Charman and Murphy 2000). For most purposes, acid soils have pH < 7.0; neutral soils have pH about 7.0 and alkaline soils have pH > 7.0. In addition there are degrees of acidity and alkalinity. Acid soils can be divided into severely (pH < 4.5), highly (pH 4.5–5.5) and moderately (pH 5.5–6.5) acid. Alkaline soils can be divided into severely (pH > 9.0), highly (pH 8.0–9.0) and moderately (pH 7.0–8.0) alkaline. Soil pH can be rapidly assessed in the field by using commercial barium sulphate soil testing kits which usually have an accuracy of about 0.5 pH units. A more accurate reading can be made by mixing a 1:5 air-dry soil sample:water extract and measuring the pH_(water) of the suspension using a portable pH meter. The most accurate reading will be by laboratory assessment of pH_(water) and pH measured in a calcium chloride solution (pH_{CaCl²}).

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The level of groundwater salinity, as well as its depth, will affect tree growth as well as water use. The following generalisations are a guide. Slightly to moderately salt-tolerant trees can be expected to take up groundwater of EC < 7.5 dS/m and use it for growth. Groundwater with EC of 7.5–15 dS/m can be used by moderately to highly salt-tolerant trees. Highly-salt-tolerant trees should be able to use groundwater of EC > 15 dS/m but growth would be expected to slow considerably as the EC rises. By way of comparison, the salinity of seawater is generally in the range EC 45–50 dS/m.

The degree of soil salinity of a paddock or other site can also be assessed by the extent of vegetative cover and the nature of plants present. For example, pasture composition may change from salt-sensitive clovers to salt-tolerant grasses (such as sea-barley grass), rushes and sedges at EC_e of 2–6 dS/m, whilst bare patches and scalding can occur at EC_e of 6–15 dS/m, with salt crusting on the surface above EC_e of 15 dS/m. Slow deterioration of the health of remnant trees on flats, along roadsides, in valley floors and on poorly-drained sites is often an indication of rising saline watertables. Mature trees are usually susceptible to relative sudden increases

in groundwater and soil salinity because their root systems cannot adjust quickly and also because many species that are impacted on tend to have low salt tolerance.

An up-to-date review of classification of saline seepage scalds is provided by Semple and Williams (2002). The difficulty in relating visual attributes (e.g. the presence/absence of indicator plants, fluffy soil surface) with results of field tests is highlighted with reference to a study of NSW sites.

1.4 Salinity and Related Stress Factors

1.4.1 Salinity

Salinity affects plant growth in three main ways:

- **Water Deficit - Osmotic Effects** — High concentrations of dissolved salts may affect the ability of plant roots to extract water from the soil, even when abundant soil water is available. This is called an osmotic effect, because the plant must obtain soil water through its roots against an osmotic (or salt concentration) gradient. Plants have to lower the water potential (i.e. increase the suction) of leaves and other tissues in order to get water to move into roots and through the stem and be transpired by the leaves. Osmotic effects are likely to occur when plants are exposed to sudden changes in the root environment, e.g. where seedlings are planted into saline soil or where saline irrigation water is applied. Water deficit symptoms may occur within days or weeks.
- **Salt Toxicity** — Unregulated uptake of salts by plant roots and the inability of plants to place these salts within the vacuoles (the major components of mature cells) of leaf cells can cause critical processes in the cell to malfunction, leading to leaf damage and reduced growth within weeks or months of exposure to saline conditions. For trees, Cl toxicity is considered more prevalent than Na toxicity.
- **Nutrient Imbalance** — Nutrient deficiencies may result because the uptake of salts (Na, Mg, Cl and other ions) may compete with nutrients (such as potassium (K), phosphorus (P) and nitrogen (N)), or due to reduced root growth with less opportunity to explore the soil, or both. High concentrations of Mg may severely reduce root growth, mainly due to induced Ca deficiency. Nitrogen fixation in legumes may also be disrupted.

Most trees and shrubs are termed **non-halophytes**. They show growth reductions with increasing salt concentrations. Typically, salt-treated plants will show a decline in growth when the root-zone concentration exceeds a threshold level. The relationship is often sigmoidal in nature but for practical purposes a two-stage linear relationship (relative growth = $100 - b$, where b is the slope of the growth-EC relationship on the declining part of the curve) or even a linear relationship (e.g. Marcar *et al.* 2003a,b) is used. Typical growth responses to salinity are shown in Figure 1.4; definition of responses amongst tree species is much less well documented than for crops (refer Maas and Hoffman 1977). In most cases, the roots of these trees try to limit how much salt enters the plant. Transport of these salts to young developing leaves is also restricted. Species and provenances that are more salt-tolerant have a greater ability to exclude salts. These trees use organic solutes (such as sugars and amino acids derived from photosynthesis) and inorganic solutes (such as K, Ca and nitrate (NO_3)) to counteract (or adjust to) the induced osmotic stress. The use of organic solutes for this osmotic adjustment will, however, deprive the plant of energy that could otherwise be used for growth.

Typical signs of salt damage are marginal or tip death of older leaves followed by the death and subsequent shedding of leaves (Photo 1.4). Newer leaves of seedlings planted into highly saline soil may quickly dry and die due to induced water-deficit. Newly planted seedlings are usually more susceptible to elevated salinity than those which have had time to adjust and develop an extended root system. Leaf damage due to direct exposure to salt is to be expected from tree exposure to sea spray and salt-laden winds, or spray irrigation using saline water.

Halophytic trees and shrubs tend to show growth stimulation at low levels of salt and growth reduction at higher salt concentrations (Fig. 1.4 – refer to line ‘C’). Whilst they also exclude salts at the roots, these plants are much better at dealing with salt accumulation in their leaves. This salt is either primarily included in vacuoles of leaf cells where it is used in osmotic adjustment (e.g. mesquite (*Prosopis*), an exotic tree) or secreted onto the leaf surface in specialised glands and bladders (e.g. athel (*Tamarix aphylla*), an exotic tree; mangroves and salt bush (*Atriplex* spp.)) or both. Salts on leaf surfaces can be washed off by rain and dew.

Both halophytes and non-halophytes can also reduce salt accumulation by shedding older leaves to ‘relieve’ the plant of its salt load, but this strategy reduces growth.

1.4.2 Waterlogging

Waterlogging is often associated with saline soils (Photo 1.5) because (i) most of the root zone becomes saturated or moist from shallow watertables and/or (ii) infiltration and permeability are low due to soil sodicity, physical barriers or other impediments. In many areas waterlogging by itself is a major problem and is often more widespread than salinity. The principal stress is an oxygen deficit (anoxic conditions), despite the variety of physical and chemical changes which can occur in waterlogged soil. Inundation or flooding will cause added plant stress and may also increase the erosion risk. The opportunity for soils to become waterlogged are greater if the watertable is very shallow, the soil texture is heavier (i.e. more clay is present) and drainage is restricted. Watertable depths are best monitored by installing piezometers.

The degree of plant damage and growth reduction will vary with duration of the waterlogging or flooding event, species and other interacting factors (e.g. degree of salinity and temperature). Waterlogging reduces shoot growth by slowing the production of new leaves, by reducing growth of existing leaves and by causing premature leaf shed. Waterlogging also reduces root growth and viability, and reduces root formation. The above effects

Photo 1.5 *E. globulus* (blue gum) planted on waterlogged saline land in WA

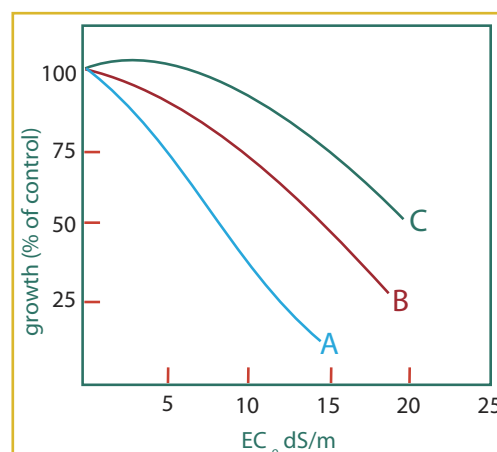
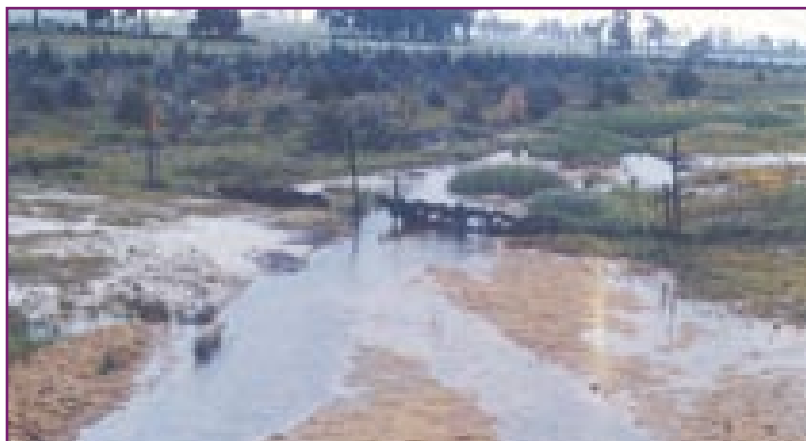


Figure 1.4. General relationships between tree growth and salinity (A: e.g. *E. camaldulensis*, B: e.g. *C. glauca*, C: e.g. *A. stenophylla*) (Graphics: RIRDC Publications Unit)



Photo 1.4 Salt toxicity symptoms on *E. brassiana* growing on a highly saline site in NE Thailand (Photograph Nico Marcar).



are mainly related directly to low soil oxygen concentrations and changes in plant hormone levels. Woody (older) roots are more tolerant of flooding than non-woody (younger) roots.

Shallow watertables (less than 2 m from the soil surface) and sodic soils (especially those with an impeding layer) tend to restrict root growth to the surface horizons. This predisposes the tree to falling over, and, in dry seasons, to drought injury. Prolonged waterlogging can predispose roots to damage from soil pathogens such as phytophthora (*Phytophthora cinnamomi*). Nutrient uptake (e.g. of N) will be reduced under waterlogging.



Photo 1.6 Surface lateral roots of *Melaleuca leucadendra* on a saline, waterlogged site in NE Thailand. (Photograph Nico Marcar)

Plants which tolerate waterlogging usually have specially adapted roots. For example, river red gum (*E. camaldulensis*) has root air channels (aerenchyma), mangroves have aerial roots and some species (e.g. *Melaleuca leucadendra*; Photo 1.6) also have adventitious roots close to the soil surface, often with air channels.

If saline soils are also waterlogged, non-halophytes will be less able to restrict salt uptake due to a lower supply of soil oxygen. Salt exclusion mechanisms rely on high metabolic activity and thus on good soil aeration. Halophytes can also be affected by this interaction. A number of examples of marked increases in foliar Na and Cl concentrations of seedlings of tree species treated with waterlogging in addition to salt are provided in the review of Barrett-Lennard (2003). These increases are often associated with more severe symptoms, and, in the longer term, increased possibilities of plant death.

1.4.3 Sodicty

In sodic soils under low electrolyte conditions Na and water can interact with clay particles, causing clay particles to repel each other and disperse. This situation can occur when water (e.g. rain or irrigation) is applied to the soil. Dispersed clay particles can then move through the soil, clogging soil pores. The main constraints to plant growth in sodic soils are:

- poor physical conditions (e.g. hard-setting surface soil), inadequate drainage and correspondingly poor aeration, and/or
- nutritional imbalances including deficiencies of P and Zn, and/or
- toxicity of specific ions, e.g. boron (B).

Factors that impede root growth include poor aeration, high soil strength, stickiness when wet and hard setting soil surfaces. Sodic soils may also develop a hard layer, due to precipitation of calcium carbonate (CaCO_3), which will severely restrict vertical root penetration.

Nutritional imbalances cause more problems on non-saline sodic soils than on saline-sodic soils. This is because in saline-sodic soils nutrient concentrations are greater because the soil pH is usually less alkaline. Many subsoils in southern Australia may have high concentrations of B. Most native tree species can tolerate quite high B levels in their leaves. Plant growth on non-saline sodic soils is usually more affected by poor physical structure than on saline-sodic soils.

1.5 Tree Planting for Productive Use and Rehabilitation

1.5.1 Water Use

There are several cases where tree planting on or near to discharge or shallow watertable locations may be beneficial. Examples include (i) where protecting stream water quality is an overriding consideration; (ii) to remove relatively fresh water in 'break of slope' situations (Silberstein *et al.* 2002); (iii) to intercept relatively fresh perched groundwater above sand plain seeps (Schofield 1992) and laterally flowing groundwater, (iv) making use of otherwise unproductive land. However, unless tree planting is extensive throughout a catchment, watertables are likely to be lowered only underneath the planted trees. Furthermore, watertables will be lowered only if trees can use groundwater directly and inflows from surrounding areas are relatively small. The presence of moderately to highly saline ($EC > 5\text{--}10\text{ dS/m}$) water will reduce the chances of successfully lowering the watertable because trees will be less able to draw on this water source and there will be a greater threat of impaired tree growth (George *et al.* 1999). In some regions (for example, parts of the wheatbelt of Western Australia) highly saline groundwater can be common and in such situations, it would be difficult for trees to have much impact on watertable lowering.

Trees are likely to use most water when they have access to good soil moisture for most of the year (e.g. in higher rainfall sites, under irrigated conditions or when planted above a shallow groundwater system) and in situations where the canopies of trees are close together (e.g. where trees are planted at spacings of > 1000 trees/ha)). Trees use much less water when they can dry out the soil profile relatively quickly and/or where they are using saline water. Tree water use is commonly estimated by measuring the flow of sap with heat pulse equipment (Photo 1.7). Limited information is available on the ability of different tree species to use groundwater of varying salinity and depth (Thorburn 1996). Although many tree species can continue to use water with an EC of $5\text{--}10\text{ dS/m}$, only the most salt-tolerant trees such as *M. halmaturorum* (salt paperbark) can use highly saline groundwater ($EC > 20\text{ dS/m}$) (Mensforth and Walker 1996). In some cases, trees planted in saline areas can use substantial amounts of groundwater; for example, a recent study on a saline site in central west NSW indicates that up to 35% of transpiration of *E. camaldulensis* trees is derived from saline groundwater with EC up to 20 dS/m (Marcar and Benyon 2000).

Different tree species grown under similar site conditions, including saline environments, generally use similar amounts of water when water use is expressed on the basis of leaf area or sapwood area (Morris and Collopy 1999; Benyon *et al.* 1999, 2001). However, the depth and spread of roots is also important in determining how much and where trees source water in widely spaced plantings. Salinity and waterlogging can lower water use of plantations by reducing tree growth rates, and hence leaf area, as well as restricting root exploration. The large differences in growth rates between species that are caused by differences in their tolerance to salt often result in large differences in water use per tree and thus per unit land area.



Photo 1.7 Heat pulse equipment installed onto the stem of an *E. camaldulensis* tree (Photograph Nico Marcar)

1.5.2 Planting Options

Dryland Sites

Salt-tolerant trees, shrubs (including *Atriplex* spp.) and grasses can be planted on or adjacent to discharge areas (seeps and scalds). Trees will survive and grow better and use more water if planted adjacent to saline seeps and scalds than if planted directly on a saline and/or waterlogged seepage area. This is because soil physical and chemical conditions are more favourable away from the seeps and scalds and tree roots may access groundwater of lower salinity. If trees planted adjacent to the seep induce the watertable to drop, the salinity of surface soil may also fall, allowing more trees, grasses or crops to be planted towards the centre of the seep. Holmgren (1994) provides an example of zonal planting.

Planting trees in dryland discharge zones can help to: (a) lower locally-high watertables; (b) reduce soil erosion and improve stream salinity; (c) provide shelter and shade; (d) provide wood products and carbon storage; (e) provide habitat for wildlife and maintain conservation values and (f) improve aesthetics and land values. One of the areas of current research interest is to predict the capacity of discharge site revegetation to reduce water, and therefore salt movement to streams, and hence assist in meeting river salinity targets set by catchment authorities.

Trees can be established in a variety of configurations on or near to salt-affected land or shallow-watertable sites. They can be planted in woodlots and blocks (typically >500 trees/ha), as shelterbelts and alleys (< 500 trees/ha), and as belts around saline seeps or scalds or scattered (<500 trees/ha) throughout a saline seep. These arrangements will be dictated by factors such as farm layout, environmental and commercial benefits sought, soil and groundwater conditions and landscape configuration and position (see for example, Abel *et al.* 1997; Bird 2000).

- **Woodlots** — These are most suited to lower slopes and slight to moderately saline discharge sites where good growth and water use can be expected for commercial production of timber, fence posts, firewood, possibly pulpwood and furniture. Planting density is flexible and dependent on rainfall and soil textural conditions but would be typically up to 1000–1200 trees/ha in high rainfall, less saline zones and up to 500–600 trees/ha in low rainfall, higher saline zones. If commercial timber production is not the aim, species of suitable salinity tolerance and found in remnant vegetation will contribute to the aesthetics and flora and fauna conservation of the area and also assist in drying out discharge sites. Perennial salt-tolerant grasses may be established and contribute to grazing value.
- **Agroforestry/alley farming** — Agroforestry and alley farming combines trees, shrubs and pastures or crops to maximise productivity and water use. This arrangement can be applied near to or on saline land (Lefroy and Scott 1994). Tree and pasture growth may be enhanced when combined with surface drainage for waterlogging control. Planting layout and density is flexible; 100 to 450 stems/ha in multiple rows up to 50 m apart will provide a satisfactory ratio of trees to pasture (Angell *et al.* 2001). Species choice is critical in saline and wet areas. Tree belts in alley systems have the potential to use saline groundwater; the widths between and within belts and likely sustainability of the system have

been modelled for soils of different texture (Fig. 1.5; Stirzaker 2002). The key issue generally is to maximise the distance between tree belts in order to reduce production losses from crops or pasture, and balance local recharge from the alleys with continued groundwater use (i.e. enhanced discharge) by the tree belts. For alley cropping to have a hydrological impact, the spacing between belts would need to be small and the use of groundwater high. However, the challenge is to maintain a high level of water use by trees by minimizing salt accumulation in the saturated zone from which groundwater is being drawn, either through salt export or by maintaining the salt at depth. These issues are discussed further below.

- **Windbreaks and Shelterbelts** — These can be planted along fence lines and at other appropriate paddock locations, and serve to increase crop and pasture production, provide shade and shelter and use some excess surface and groundwater.

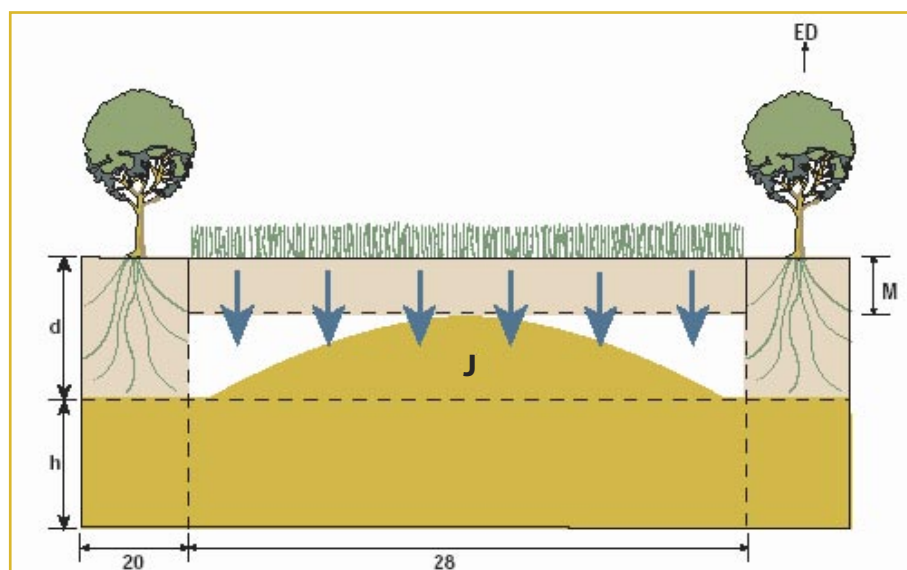


Figure 1.5 Schematic outline of tree belts planted in a location where tree roots have access to the watertable (the dark shading represents the saturated zone). J =the annual drainage below the crops; d =depth to the watertable below the trees; M =the depth of the watertable at the midpoint between the tree belts; h =the height of the watertable above an impermeable layer; E =the annual water use by trees in excess of rainfall; and D =the half-width of the tree belt. Redrawn from Stirzaker et al. (1999). Source: Trees, water and salt, RIRDC Pub. No. 01/086)

In wide-spaced agroforestry plantings, pastures should not be grazed until trees are well above grazing height; cattle, in particular, can damage relatively old trees. Holmgren (1994) provides information on use of *Casuarina* spp. for shelterbelts and grazing.

Recent attempts by farmers in WA to use one or more rows of salt-tolerant trees (e.g. *E. camaldulensis*, *E. loxophleba*, *E. occidentalis*, *E. sargentii* and *E. spathulata*) spaced 15–30 m apart have met with some success in lowering saline (EC up to 30 dS/m) watertables under the trees and in the alleys between the tree rows (George *et al.* 1993; Lefroy and Scott 1994). However, pasture growth in the alleys has often been relatively poor due to competition from tree roots, particularly in narrower alleys and on sites which do not permit rapid downward growth of tree roots. There are also a number of constraints to continued growth and water use of trees in such locations where they are drawing on saline groundwater; a detailed example where long-term sustainability has been questioned due to increases in salt accumulation in the root-zone is provided by Stolte *et al.* (1997) for a 15-year-old agroforestry planting of eucalypts on a saline discharge site near Narrogin, WA.

Salt-tolerant trees can be introduced to rehabilitate remnant native vegetation and important biodiversity areas subjected to salt damage. An example is the introduction of casuarinas and melaleucas on land surrounding Lake Toolibin near Narrogin, WA (one of the largest lakes to have become salinised in WA) in an attempt to lower saline watertables in conjunction with drainage and pumping schemes (Froend *et al.* 1997).

Irrigation Sites

Planting trees in irrigation areas that are salt-affected or underlain by shallow saline groundwater can also help to lower watertables, through control of recharge (e.g. from channels) or withdrawal from groundwater. The impacts are likely to be local due to lack of significant slope and low water movement (low hydraulic conductivity) in the heavier-textured soils that predominate in these areas. The essential hydrological issue in establishing trees in such areas is whether their roots can grow deeply and use saline groundwater at reasonably shallow depths over the medium to long term (over a rotation cycle (e.g. 20-30 years)).

When trees take up water from the capillary fringe (the zone just above the watertable where soil is saturated) they create a localized depression in the watertable which induces a flow from surrounding areas at a rate proportional to the saturated hydraulic conductivity of the soil (largely dictated by the soil texture and depth) and the gradient created by the localised decline in the watertable (Stirzaker 2002). If salt accumulates beyond species-specific thresholds, then growth and water use are lowered (Feikema *et al.* 1999; Heuperman 1999). Watertables will be lowered more effectively by trees planted on light-textured than on heavy-textured soils because trees will use groundwater more effectively and the rate of water movement in sandier soils is faster. The watertable under an 85 m wide, 20-year-old *E. grandis* plantation on a heavy-textured soil in northern Victoria was lowered by up to 5 m with an effective zone of influence extending to 30 m away; modelling suggests that this zone could extend out to 100 m with light-textured soils (Silberstein *et al.* 1999). At a site near Deniliquin, NSW, with a clayey soil, it was difficult for roots of *E. grandis* to penetrate the clay, saline subsoil (Polglase *et al.* 2002). In addition, the capacity of trees to use groundwater can vary between species. For example, *Corymbia maculata* derived more of its water from groundwater than did *E. grandis* on a sandy, shallow-groundwater site near Deniliquin (Polglase *et al.* 2002).

Saline drainage water and groundwater can be directly applied to tree plantations as long as salt build-up is effectively minimised through the provision of adequate leaching of salts (Heupermann 1991). This saline water would otherwise have flowed to streams and eventually rivers, by sub-surface seepage or deliberate drainage disposal. In the Serial Biological Concentration (SBC) approach which has been piloted at Tatura in northern Victoria (Heath and Heupermann 1994), the volume of saline water applied as irrigation is successively reduced (and thus its salinity increased) by its application to plants (*E. camaldulensis*, saltbush) with increasingly higher salt tolerance. This approach offers scope for decreased reliance on evaporation basins and conjunctive use of saline groundwater in irrigation areas.

Commercial plantations or woodlots offer opportunities for an economic return in addition to potential reductions in watertables. Planting trees as shelterbelts, on the borders of paddocks and along water channels can also be beneficial. Opportunities

to grow commercially-valuable trees fast enough for a commercial return and on a sustainable basis are greater where groundwater is not too saline ($EC < 5 \text{ dS/m}$) and not too deep ($< 4\text{--}5 \text{ m}$).

1.5.3 Sustainability

One potential longer-term problem as trees transpire saline [soil or ground] water is that salts accumulate in the soil around their roots (Thorburn 1996; Stirzaker 2002). This may result in reduced tree growth and water use, and perhaps eventually tree death. Current evidence indicates that salts can build up during dry periods, within or just below the zone of actively growing tree roots, especially in clayey soils where watertables are shallow and saline. However, if there is sufficient leaching of salts during heavy rainfall events, coupled with improved drainage and lateral subsurface flow of water, the potential for such salt accumulation is minimised, especially in lighter soils and where watertables are deep. On-going research at a eucalypt plantation site near Kyabram in northern Victoria, and associated modelling, confirms that long-term sustainability relies on leaching and diffusion of salt from the root zone to balance salt accumulation processes (Vertessy *et al.* 2000). Another factor to consider if salt accumulation is considered to be a potential threat is the anticipated period of rotation for the plantation. Results from modelling suggest that the build up may not reach critical levels till about the time of plantation harvest (Silberstein *et al.* 1999).

On the basis of modelling studies, Stirzaker (2002) concludes that tree plantations established on shallow, saline ($EC > 3 \text{ dS/m}$) groundwater are unsustainable over the long-term due to salt build up, unless aided by groundwater pumping or drainage. In reality, however, salt is usually reasonably mobile within tree root-zones and this will mitigate build up to unsustainable levels. There are many examples of older (10–20 year) plantings in such environments which are reasonably healthy with moderate growth rates, depending on species and location. However, in environments where there is shallow, highly saline groundwater in clay-dominated soils on flat landscapes, there is evidence of dieback of planted trees, especially those that have insufficient salt tolerance.

1.5.4 Natural Ecosystems

Naturally-occurring saline ecosystems include samphire communities, saltbush shrublands, sedgelands, eucalypt woodlands and forests, and paperbark forests. It is valuable to evaluate processes occurring in saline discharge areas that sustain plant communities in order to develop new farming systems for saline environments. The capacity of vegetation in saline areas to maintain transpiration is countered by the potential for salt accumulation in the root zone; these ecohydrological processes can be quite dynamic both in space and time. By understanding the dynamics of salt, water and nutrient movement in these environments, it should be easier to develop appropriate agricultural/agroforestry systems that are sustainable in the long-term, productive (and economically attractive) and have potential application for rehabilitation on other sites.

One example is that of *M. halmaturorum* (swamp paperbark) communities in the Upper South East of SA, which is dominated by remnant sand dunes and interdunal

flats. This species is well adapted to occasional inundation, waterlogging and salinity. The major processes operating have been evaluated in a series of studies (Mensforth and Walker 1996). As salt accumulates near the soil surface in summer, the surface roots die so that water is extracted only from lower in the soil profile. In winter, rainfall recharges the groundwater, leaching salt from the upper soil profile and causing the moderately saline groundwater to rise to the soil surface. This flushing of the soil is vital to the tree's survival. In response to the waterlogging, the roots die back to near the surface. Subsequent evapotranspiration then causes the watertable to drop quickly and the roots grow again. In periods when salt accumulates in the root zone between the capillary fringe and the soil surface, the tree reduces its leaf water potential to very low levels, and by doing so it can continue to take up water from saline soils and groundwater. Other plants use the same mechanism to 'squeeze' water from a dry soil profile.

The capacity of plants to lower their internal water potential is a key mechanism that enables them to keep taking up water. Another example is that of native *E. largiflorens* (black box) woodlands on the floodplain of the lower Murray River, SA that are able to extract saline groundwater up to EC of 40 dS/m, whilst that of *E. camaldulensis* (river red gum) ceased at 30–35 dS/m (Thorburn *et al.* 1993). But in both cases, unless sufficient leaching of salts takes place, salinity-induced deaths could occur.

The challenge is to determine what the constraints are to building robust agricultural/agroforestry systems for saline land and to understand the role of different types of vegetation to influence the capacity for long-term sustainability and rehabilitation.