



The JVAP Research Update Series No.1

Trees, Water and Salt:

An Australian guide to using trees for healthy catchments and productive farms



**JOINT
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Natural Heritage Trust
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Trees, Water and Salt

An Australian Guide to using Trees for healthy catchments and productive farms

The environmental benefits of growing trees on farms are universally recognised. To achieve these desired effects, plantings must be well planned. Land managers wanting to address problems of salinity and waterlogging need answers to six key questions:

- What area of a catchment needs to be planted?
- Where is the best location in a catchment to plant?
- Should trees be arranged in blocks or belts?
- What is the time interval between planting and seeing results?
- How effective are particular farm forestry designs in different settings?
- How are appropriate species and management practices chosen?

A valuable new book provides information needed to answer these questions. Entitled *Trees, Water and Salt: an Australian guide to using trees for healthy catchments and productive farms*, it has been written by researchers from CSIRO Land and Water and CSIRO Forestry and Forest Products and other agencies (see page 21), and produced by the Joint Venture Agroforestry Program. The book is edited by Richard Stirzaker, Rob Vertessy and Alastair Sarre.

This research update outlines the book's key messages. The detail is important, so those considering planting trees to address salinity are urged to consult the book.

To answer the six questions above, we need to understand the whole picture from the hydrological behaviour of a catchment to the performance of a single tree in a paddock.

Trees, Water and Salt is designed to make this current scientific knowledge available to land managers. The contents of the book will:

- Provide a design framework for tree planting to combat salinity
- Outline basic hydrological concepts, giving the necessary technical background to interpret the rest of the book
- Give an overview of the ways different catchments respond to planting strategies

- Present descriptions of planting designs appropriate to various situations.
- Offer suggestions regarding tree species suited to specific conditions.

The format is clear and easily accessible, and the book is fully illustrated.

The problem, and how agroforestry can help

The replacement of native vegetation with crops and pastures that use less water has resulted in rising groundwater levels, causing salinity damage over wide and growing areas. The problem can be alleviated by tree planting, but this requires careful planning based on knowledge of the affected catchment.

Around 2.5 million hectares of farming land in Australia is now salt-affected, and this area could increase sixfold in coming decades despite current efforts to slow the spread. The water in some Western Australian rivers is no longer fit to drink, and several important eastern rivers face the same fate.

Clearing native vegetation for crops and pastures causes this situation. Unfortunately, three features of the Australian landscape make it particularly susceptible to salinisation:

- Native vegetation, adapted to Australia's highly variable climate, is equipped to use water when it is available, including that stored deep in the soil. Under this vegetation, leakage of rainfall is low. Leakage is generally much higher under the shallow-rooted seasonal crops and pastures that have replaced it.
- Salt from the sea carried in rainwater has accumulated in the soil profile over a very long time. Rising watertables dissolve salt and bring it back towards the surface. Salty water also starts to move laterally, forming saline seeps and entering rivers.
- Horizontal movement of water through the soil is generally very slow because the land tends to be flat and the soils not very permeable. Hence, when the vegetation does not use all the rainfall, watertables start to rise.

Clearly, reintroducing trees to the landscape can help alleviate salinity and waterlogging problems. But to be effective this needs careful planning. The first three stages in planning a catchment tree-planting strategy to address salinity involve utilising the conceptual knowledge explained in this book in conjunction with local expert support to:

- Determine the scale of the aquifer system and the discharge capacity — this helps to determine the area of planting needed to have the desired effect and the time-scale for realising the benefits.
- Estimate current groundwater recharge in the catchment — from predicted long-term leakage rates for each land use and the area under each use.
- Identify a target — for example, to reduce leakage to a level that will result in no further rise in the watertable.

Once conditions are identified and a target has been decided, the principles explained in the book can be used to help:

- Assess the best locations and arrangements for tree planting.
- Design the most efficient revegetation strategy to meet the recharge target. There are four main agroforestry designs discussed in the book:

- 1 **Alternating woodlots with agriculture (phase farming)** – woodlots are used to control recharge by drying out the soil profile– appropriate for deeper soil profiles with heavy textured subsoil.



- 2 **Hill-slope tree belts** – appropriate for recharge and discharge control in hilly local flow systems.



- 3 **Mixing tree-belts with agriculture** – the suitability of either tree-belts or blocks can be determined to reach a given leakage target in recharge areas where watertables are still relatively deep but rising.



- 4 **Planting shallow, saline watertables** – trees planted in such environments can lower the watertable locally, primarily through reduced recharge. This may result in reduced saline discharge but the design can only be applied in areas where the water is not too salty and lateral water movement prevents salt accumulation.



Design Principles for Agroforestry

Protection of the land resource — from wind and water erosion as well as from salinity — is a major incentive to plant trees. There are others as well, notably:

- Products such as wood, pulp or eucalyptus oils can provide new income streams for farmers.
- Agroforestry can increase farm productivity by providing shelter for stock and crops and alleviating waterlogging in low-lying paddocks.
- Tree planting can enhance biodiversity and the aesthetic appeal of the landscape.

Further information about how to design agroforestry systems to meet multiple objectives can be obtained from:-

Abel, N., Baxter, J., Campbell, A., Cleugh, H., Fargher, J., Lambeck, R., Prinsley, R.T., Prosser, M., Revell, G., Schmidt, C., Stirzaker, R. and Thorburn, P. 1997 *Design Principles for Farm Forestry- A guide to assist farmers to decide where to place trees and farm plantations on farms*. Canberra, Rural Industries Research and Development Corporation.



New Guidelines Series-

As a follow up to the best seller *Design Principles for Farm Forestry* the JVAP is producing a series of guidelines to help land managers decide how to integrate trees on farms for multiple benefits. *Trees, Water and Salt* is the first in this series. Other guideline books available in early 2001 are:

- *Trees for shelter: a guide to using windbreaks on Australian farms*
- *Farm Forestry Site Selection Manual*

JOINT VENTURE AGROFORESTRY PROGRAM (RIRDC/LWRRDC/FWPRDC)

Since 1993, JVAP has led Australia in the development and dissemination of research and practical information to underpin new sustainable farming systems incorporating perennial woody vegetation.

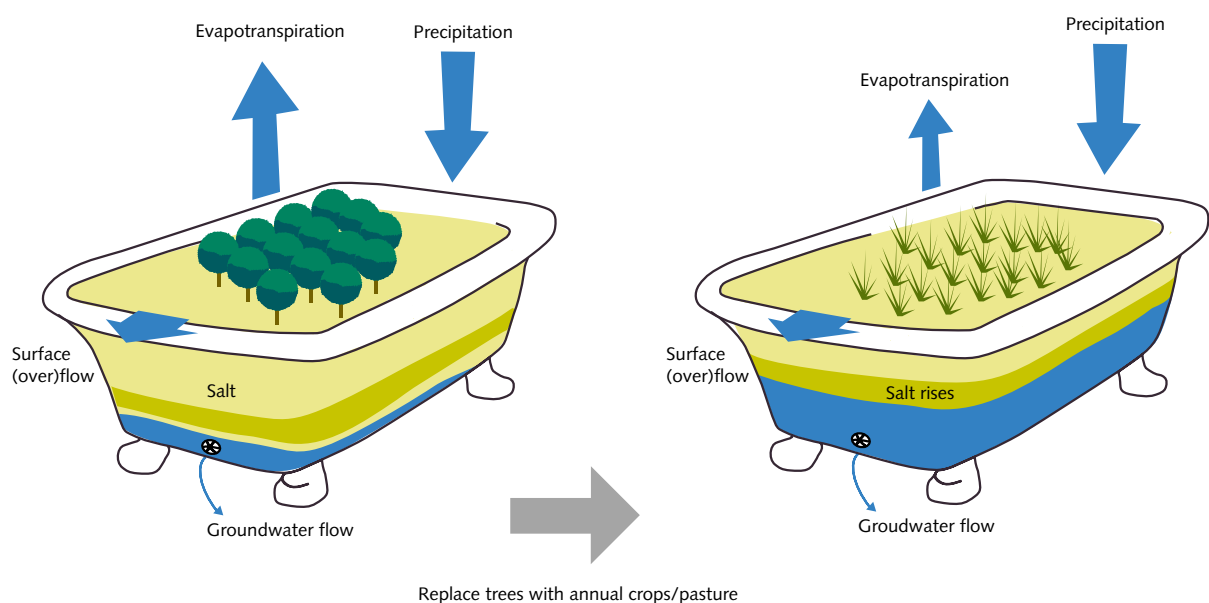
The program focuses on commercially driven tree production systems for addressing land degradation issues. It is developing new tree-based industries for integration into low to medium rainfall farming systems. The program aims to deliver the following outcomes:

- Targeted strategies for implementation of farm forestry
- More sustainable management of natural resources eg. soil, water and biodiversity
- Optimised productivity of crops and pastures
- Optimised direct returns from tree products
- Cost effective multi-purpose agroforestry systems to meet commercial and environmental objectives.

The soil, water, plant connection

A catchment may be thought of as a bathtub filled with soil and tilted on a gentle incline. Water "leakage" past the root zone of the plants is like a dripping tap. Under Australia's natural evergreen and deep rooted vegetation this rate is very low. As a consequence the watertable is deep beneath the surface, and what little groundwater there is flows slowly, as if the bath has a small drainage hole (or discharge). All rain water carries small amounts of salt which is stored deep in the soil.

When the deep rooted vegetation is removed, the shallow rooted grasses which replace it do not use as much water, and leakage past the root zone increases. Using the bathtub analogy, - the "tap" now drips at a faster rate. If this rate is greater than the discharge capacity of the bathtub (catchment) the watertable rises, dissolving salt as it does and bringing it near the surface. The result is that the bathtub fills until it overflows at its lower edge— meaning shallower watertables, waterlogging and salinity, as well as longer periods of stream flow, now carrying salt, and increased likelihood of flooding.



The leakage under native vegetation is 1–10 mm per year and under annual crops and pasture about 10–150 mm per year. Continuing the bathtub analogy, if this rate exceeds the outflow capacity of the plug hole, then water will rise in the bath. In catchments, the critical outflow rate is called the discharge capacity, and when the leakage from vegetation exceeds it we get rising watertables. It is this connection between input (leakage) and output (discharge capacity) which leads to the enormous problems we have created for ourselves right across Australia which show up as saline seeps, waterlogging and discharge of salty water into streams.

This simple model helps to illustrate the hydrological processes at work in a catchment. However, it belies the extreme complexities in understanding exactly what is going on underneath the ground surface, simply because we cannot see, and cannot measure the water and solute flowing through the soil in any precise way.

The salt content of the soil adds another layer of complexity. Virtually all soil has some soluble salt in it which is derived from a number of sources. Huge quantities of salt have built up over long periods, especially in Western Australia (WA) where up to 10,000 tonnes is stored under each

The complexity of catchment hydrology can be summarised as follows:

1. The spatial scale of the catchments we want to study and manage varies from less than 1 km² to 1000's of km².
2. The catchments are filled with internal heterogeneity, or “patchiness” of vegetation, soils, slopes, and basement rock formation.
3. They carry not only water, but also salt and nutrients.
4. There can be a number of groundwater interactions below the surface which are not visible, and can only be inferred from indirect measurements.
5. The time scales for hydrologic processes can be very short or very long – from storm events to 100s or 1000s of years.
6. There is enormous uncertainty in virtually every quantity associated with the characteristics of any catchment.

hectare of wheat/sheep country. Most of this salt is deep in the soil, but it is highly soluble, and when water passes through the salt bearing soil it is easily mobilised. When the catchment “bathtub” fills, the water level rises through the salt bearing soil, and the salt is dissolved and brought closer to the surface. When the, now salty, watertable reaches stream beds, the streams run more frequently and with higher salt content. Where the soil surface is within about 2 m of a saline watertable, surface evaporation drives capillary action bringing water upwards from the watertable, leading to ever increasing salt accumulation at the surface.

The rate at which water flows through soil depends on its hydraulic conductivity, which can vary from less 1 mm per day for clays to several metres per day for sand and structured soils.

Key influences on catchment hydrology are the underlying aquifers — saturated geological structures through which water can move relatively freely. The aquifers under farmland can cover much larger areas than the surface

catchment, and there is a wide variation across a catchment in the rates at which rainwater leaks through the soil to recharge aquifers. Areas where leakage is greatest may offer the opportunity to achieve a relatively large impact on groundwater recharge with tree planting.

Trees can take water from the watertable directly, or indirectly via the capillary effect, and from unsaturated (moist) soil above the watertable. Planting trees on former pasture or cropping land gives them access to soil moisture, and possibly an elevated watertable, that would not have been there if the native vegetation had not been cleared. Once they have removed the excess water, their growth will slow to a rate sustainable by rainfall alone, which may be significantly lower.

How rainfall is distributed through the year has important influences. In areas with a Mediterranean climate, such as southern WA, most rain comes in winter and water stress in summer can restrict tree growth. Also, importantly, the soil can quickly become saturated in winter. As hydraulic conductivity increases rapidly with water content, this may result in rapid movement of groundwater downslope, with adverse consequences lower down in the landscape. The soil is less likely to become saturated in regions with a similar annual rainfall but a more even distribution through the year, so water will usually move more slowly downslope there.

Predicting catchment response to tree planting

The first vital step in undertaking a tree planting program for salinity control is to obtain information on key features of the catchment that will influence the response. These include the discharge capacity, variations in groundwater recharge rates across the catchment, the scale of the groundwater systems and the salinity of the groundwater. Generally, the smaller and more permeable a groundwater system, the faster will be its response to revegetation. Relatively fresh and shallow watertables provide the best opportunities to use tree belts to intercept groundwater recharged from upslope. Intermediate and regional scale groundwater systems usually have a low discharge capacity, and most of the landscape may have to be replanted to significantly reduce outflows of saline water. Reclamation of already salinised land there may take a very long time.

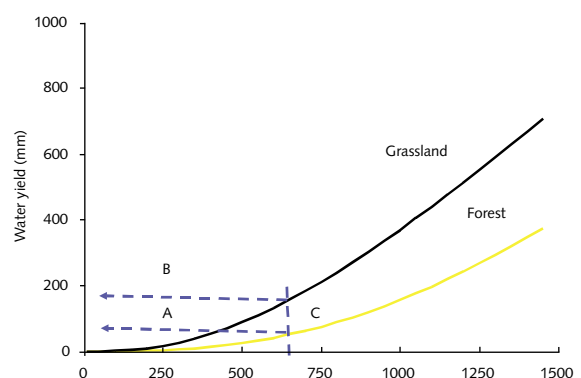
Responses of catchments to tree planting vary enormously. In some cases, local strategic plantings will reduce waterlogging and salinisation almost immediately. Elsewhere, most of a catchment will have to be replanted to have a substantial impact on salinity and waterlogging. Salinity usually takes decades to appear after land clearing and may take many more decades to abate after revegetation. In tackling the problem in a catchment, the cooperation of many farms will usually be required.

Differences in soil and aquifer properties, catchment size, landscape gradients and salt storage contribute to this diversity of response. A key influence is the aquifer's discharge capacity — the maximum amount of water that it can discharge when full. As described previously, recharge in excess of this will result in rising watertables, which may produce damaging groundwater outflows at the land surface, such as saline seeps.

Average annual rainfall strongly influences the nature of the outflows. Where it is above about 900 mm, salt will have been flushed from the soil; hence the groundwater that emerges is generally fresh. In drier areas the native vegetation's water use will have prevented such flushing, so rising

watertables following clearing bring salt to the surface. Therefore, in wetter catchments the main hydrological issue associated with tree planting is a reduction in fresh streamflow while in drier catchments it is salinity control.

In the lower rainfall catchments, the leaf area index (LAI) — the ratio of the area of leaves to that of the ground covered — of the native vegetation was about that needed to utilise all the rain that fell. The reduction in LAI following clearing closely matches the boost to groundwater recharge.



The relationship between annual rainfall and catchment water yield under grassland and forest. In high rainfall country, where the concern is over streamflow reductions due to afforestation, this is a useful and robust relationship for estimating impacts. For instance, at 700 mm of rainfall (C), a grassland or previously cleared site may yield about 190 mm of runoff (B), while a forested catchment may yield only 60 mm (C); intermediate levels of afforestation would result in a proportional decrease between these two yield values.

Designing tree planting for salinity control requires an understanding of:

- the discharge capacity of the aquifer
- how recharge rates vary across the catchment
- the scale — local, intermediate or regional — of the groundwater systems
- the salinity of the groundwater.

Knowledge of how leakage is distributed over a catchment is very important. For example, if it is evenly distributed, half the catchment will have to be planted with trees to reduce overall leakage by 50%. But if half the recharge occurs on 30% of the land area, planting only that part of the catchment will have the same impact.



Examples of catchment types, appropriate replanting regimes and prospects for salinity control include:

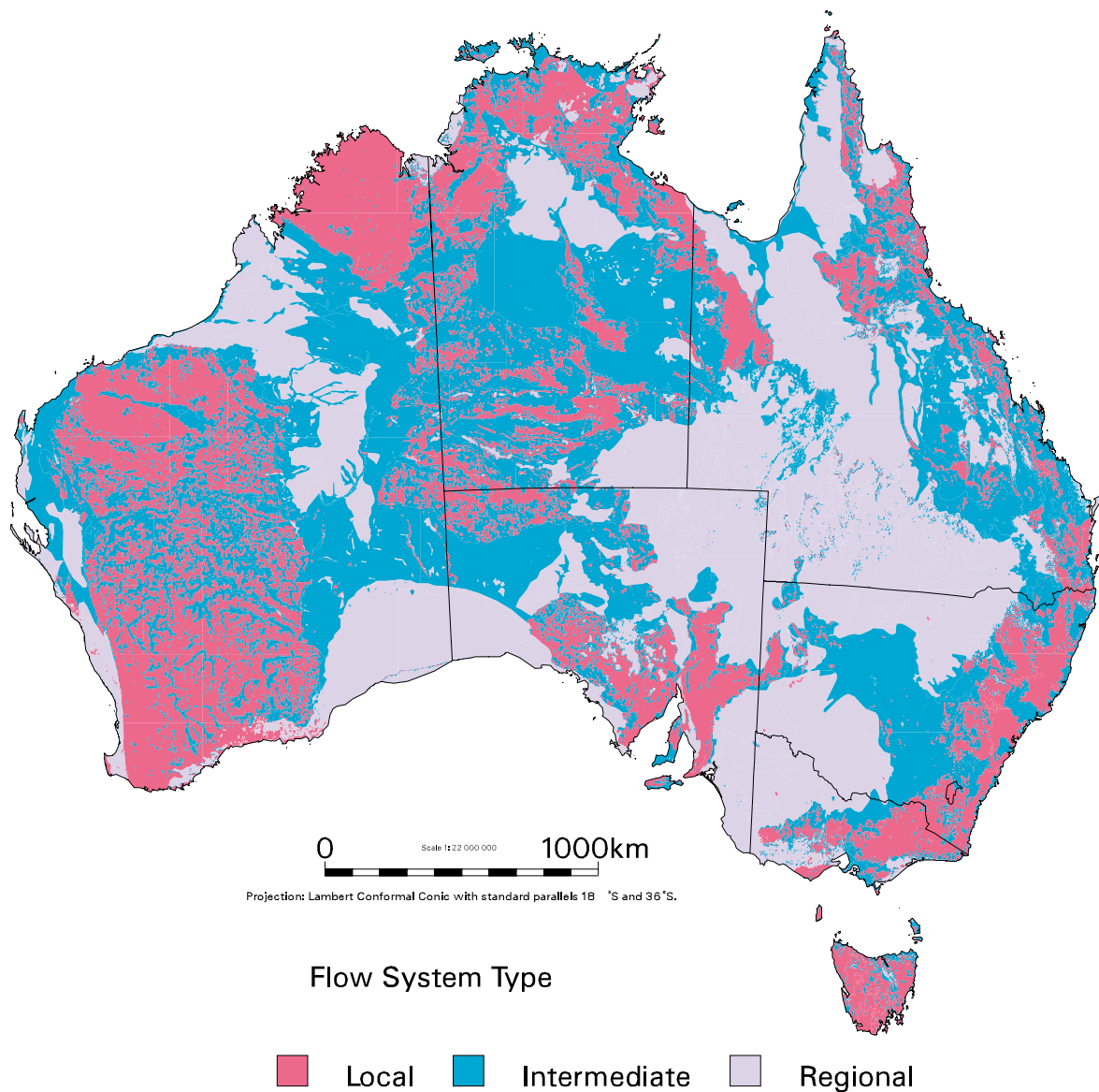
- *Local flow system catchments with a high discharge capacity (1–3 km horizontal scale).* Most commonly characterised by hillside seeps, these are relatively responsive to revegetation. Alley farming, tree belts or even widely scattered trees can often provide sufficient recharge control.
- *Local flow system catchments with a low discharge capacity (1–3 km horizontal scale).* An example is ‘break of slope’ catchments where discharge is controlled by the topographic gradient. Extensive recharge control is needed to limit waterlogging and salinisation. Alleys may have to be closely spaced and/or phase-farmed with perennial, high-water-use crops or pasture, or trees planted over most of the catchment.
- *Intermediate flow system catchments. (5–10 km horizontal scale).* Most of these systems require significant proportions of the landscape to be replanted to reduce outflows of saline water. The most dramatic and intractable dryland salinity in WA is associated with one catchment type in this category, characterised by discharge into low-lying areas such as broad valley floors. Extensive tree planting, at levels approaching the original cover, is required to control watertables. Alley farming with closely spaced trees, combined with

perennial pasture in the alleys, may achieve sufficient recharge control to contain the spread of salinity. Deep surface drains or groundwater pumping and saline disposal may have to be considered for managing discharge areas.

- *Regional flow systems. (greater than 10 km horizontal scale).* Some of these systems recharge in higher rainfall areas, providing largely fresh groundwater that can be utilised for town supplies and agriculture. Where recharge control is required, levels of tree cover approaching the original will be needed in the recharge areas. If deeper groundwaters are relatively fresh, pumping to control water levels and provide irrigation to the trees may be an option.

Significant work has been undertaken to establish the distribution of these aquifer types across the Australian landscape.

Australian Groundwater Flow Systems Contributing to Dryland Salinity



National Land & Water Resources Audit
A program of the Natural Heritage Trust

Sources: AUSLIG: Coastline/State Boundaries
AUSLIG: 9 Second Digital Elevation Model
AGSO: BMR Record 1986/27 Regolith Terrain Map Australia
(1:5 000 000)
AGSO: BMR 1976 Geology of Australia (1:2 500 000)

Rotating woodlots with agriculture



Alternating woodlots with agriculture (phase farming) – woodlots are used to control recharge by drying out the soil profile– appropriate for deeper soil profiles with heavy textured subsoil.

A proposed new 'phase farming' system for addressing salinity involves growing woodlots in rotation with crops or pasture. The woodlots can 'mine' soil water that has built up during the agriculture phase. Deeper profiles with heavy-textured subsoil offer the best prospects; a typical rotation might be three to five years of cropping/pasture between woodlots, with stored water giving the trees two to three years of enhanced growth. Here the focus is the role that woodlots play in controlling the local hydrological balance through recharge control.

Woodlots are blocks of tree plantings. The proposition that woodlots can be used in rotation with agriculture opens up challenging possibilities for achieving hydrological control while retaining traditional agriculture.

Growing woodlots has been adopted widely as a way to reintroduce trees into the Australian landscape for a variety of purposes, including lowering watertables. The build-up of soil water during cropping and pasture growth, and nutrients that have been added in fertilisers, often give woodlots planted on farmland an initial growth boost. However, their productivity may decline sharply once they have used up these resources.

The proposed approach, which is yet to be tested experimentally, involves rotating woodlots with agriculture. A woodlot can produce a tree crop while drying out the soil. Then crops and pasture can be grown on the same land until the soil water store is replenished again to the point where planting trees again becomes necessary to stop excessive groundwater recharge. Such woodlots can be moved around a farm to 'mine' water, thereby increasing the impact on recharge.

The following questions need to be considered in determining whether such a system is appropriate for a particular area, and the best length of the tree and agriculture phases:

- For what length of time will stored soil water from the preceding agricultural system enhance a woodlot's productivity?
- How long will it take for groundwater recharge to be minimised after a woodlot is planted?
- Once the trees have been harvested, what is the interval before soil water accumulates to levels where groundwater recharge again becomes a problem?

The JVAP is currently conducting research which considers products deriving from such systems.

Summary of responses to woodlots in two climates and seven soil/groundwater combinations.

Response	Scenario*		
	1	3	6
Recharge under cropping/pasture (mm/yr)	21	7.5	1
Time to recharge control (years) (water-mining phase)	2–3	1–2	1
Time to equilibrium with rainfall (years)	2–3	3	2
Time to full recharge following woodlot harvest (years) – groundwater protection phase	4	5	12

*Scenario 1 = 2 m sand, 3 m sandy loam (Merredon climate); 3 = 1 m sand, 2 m clay (Merredon climate)
6 = 0.5 m light over 2.5 m heavy clay (Merredon climate).

Little experience is available from actual plantations to answer these questions, so researchers have used a complex ‘ecohydrological’ model to predict hydrological and tree growth responses on a range of soil types. Two climate scenarios were tested — one with 70% of the 320 mm average annual rainfall coming between April to September and the other with a uniformly distributed 370 mm rainfall. Therefore although both scenarios simulated very low annual rainfall, the distribution of rainfall was quite different.

Major conclusions from the study are that:

- Very shallow or very sandy soil profiles require almost continuous protection with trees; the risk to groundwater associated with any period of cropping is not worth taking.
- Deeper profiles with heavy-textured subsoil offer the opportunity to alternate woodlots with crops and pasture. A typical rotation might be 3–5 years of cropping/pasture between woodlots, with the woodlots enjoying 2–3 years of enhanced productivity due to the stored moisture. The actual length of the woodlot rotations will depend on economic and silvicultural considerations. A real risk exists, though, that trees will die in drought after the stored water has been taken up; this should be considered in deciding rotation length.
- Woodlots able to tap fresh watertables can be very productive and sustainable with or without a crop/pasture phase. Planting woodlots over saline watertables, however, is risky because salt will build up in the root zone.

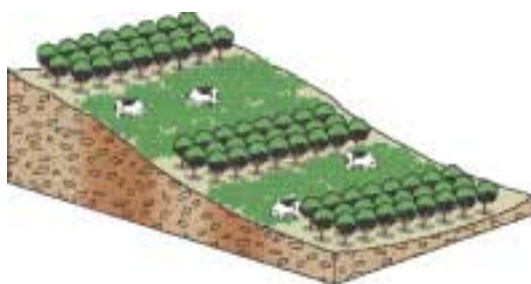
Factors in designing strategies for phase farming with woodlots

- soil texture and depth
- groundwater quality
- degree of recharge control needed to protect the land or streams
- the woodlot rotation period required for the intended forest product.

Based on these considerations, a land manager can calculate the area that should be occupied by trees at any time. Woodlots can then be moved around the land in a sequence. The soil water mining and groundwater protection potentially offered through this agroforestry strategy could significantly reduce the areas of land required under trees relative to the equivalent protection afforded by continuous forestry. For instance, in some cases a 50% recharge target can be attained by planting 25% of the land with such an agroforestry system.

An important effect of a woodlot is to ‘mine’ water that has accumulated deep in the soil under annual crops or pasture. The ‘buffer’ created will take several years to refill once the trees are removed. So a worthwhile strategy may be to grow short-rotation woodlots alternately with crops, and move the temporary tree cover around the landscape.

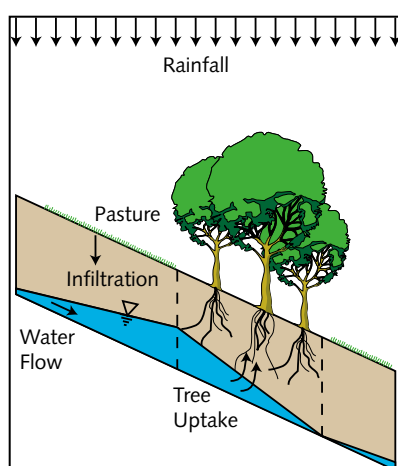
Hill-slope tree belts



Hill-slope tree belts – appropriate for recharge and discharge control in hilly local flow systems.

In hilly local flow systems, trees planted in belts on hillsides can take up water that would otherwise contribute to waterlogging or salinity problems downslope. Requirements include slope and soil conditions that result in lateral flow shallow enough for the trees' roots to reach, and water fresh enough for healthy tree growth. Designing tree belts requires information on the amount of water flowing downhill and how much the trees can use.

By intercepting water flowing through the soil down hills, belts of trees can prevent or reduce salinity and waterlogging problems further downslope. As the trees will have access to more water than is available from rainfall alone, they may also grow faster.



Tree belts may be established on hillslopes perpendicular to the slope of the hill to capture water flowing from upslope, supplementing rainfall and enhancing growth while at the same time alleviating waterlogging and salinity downslope.

Research combining field observations with computer modelling has provided guidance on how to design plantings to maximise water use — keeping groundwater recharge as low as possible — and obtain maximum tree growth. Key design considerations are the position of tree belts on the slope, the width of the belts and their distance apart.

This approach - used in isolation- is relevant only to local groundwater systems - where the area affected by waterlogging or salinity is in the same locality as the tree plantings . The water the trees draw on comes from rainfall not utilised by crops or pasture upslope.

Requirements for successful plantings are:

- sufficient slope, and sufficiently permeable soil, for lateral flow to occur;
- lateral flow shallow enough for the trees' roots to reach; and
- water fresh enough for healthy tree growth.

Those designing hillside tree belts need to know how much water will be available from upslope, how fast it will be delivered, and how much water the trees can use. Data required are:

- *an estimate of the hydraulic conductivity of the soil.* This ranges from around 1 metre per day for sandy topsoil to 1 mm per day for clay, with loam in between at about 0.1 metres per day. Expert knowledge is required for an accurate assessment.
- *an estimate of the length of the wet season.* Local knowledge or the Commonwealth Bureau of Meteorology can provide this.
- *an estimate of the thickness of saturated flow that can be tolerated.* The goal here is to ensure the trees and the pasture between the tree belts are not adversely affected by waterlogging.
- *an estimate of drainage below the root zone of the pasture or crops.* This requires expert knowledge, and will vary with management of the upslope areas.
- *likely groundwater use by trees at the selected location.* This is difficult to ascertain, but an estimate is needed to determine how wide the belt must be to utilise all the available water.

Tree belts are likely to do better — and therefore take up more water — lower in the landscape than higher up. This is partly because soils generally become deeper with distance downslope. The other contributing factor is a larger upslope area, making more water available to the trees; for the same reason relatively widely separated belts will do better than those planted closer together. Salinity and waterlogging are, however, more likely to be problems in lower areas — placing a limit on how far downslope tree belts should be located.

Decisions on tree belt width should take account of the fact that trees in the middle of the belt have less access to the extra water, and to light, than those at the edge. As a result, they will grow more slowly and use less water.



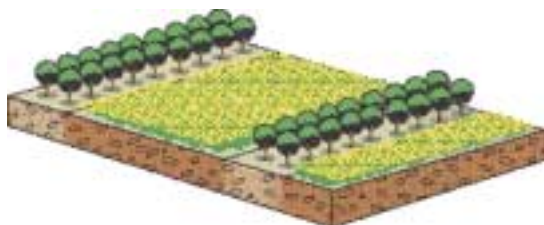
The plantation at Warrenbayne in northeastern Victoria, planted at the break of slope to intercept water flowing from upslope. The waterlogging-prone area can be seen as the brown area downslope of the plantation.

Guiding principles for planting hill-slope tree belts are:

- the steeper the slope the greater the discharge capacity, the further apart the belts *can* be, and the wider the belts *should* be;
- the greater the drainage from pasture the closer the belts *should* be;
- the higher the groundwater uptake, the narrower the belts *can* be; and
- the shorter the wet/winter period, the closer the tree belts *should* be.

On slopes, belts of trees can ‘capture’ water as it moves downhill, and so have an impact over an area considerably greater than that planted. Similarly, lines or clumps of trees surrounded by cropping or pasture land will take water from beyond the area of their own canopies.

Mixing tree belts with agriculture



Mixing tree-belts with agriculture – the suitability of either tree-belts or blocks can be determined to reach a given leakage target in recharge areas where watertables are still relatively deep but rising.

Rain-fed tree belts in recharge areas of catchments can make a useful contribution to reducing inputs to groundwater. Because the roots spread into the surrounding soil their impact on recharge extends beyond the belts, but so does their negative influence on crop and pasture growth. Researchers have devised an easy way to determine whether tree belts or woodlots are likely to give the best overall result in a particular situation. This section targets flatter terrain in recharge areas where lateral water flows are not appreciable.

Trees spread across a catchment in belts are likely to grow faster and have a bigger impact in reducing groundwater recharge than the same number of trees in a woodlot. The drawback, though, is that crop and pasture growth may be reduced over substantial areas because of competition from the trees for water, nutrients and light.

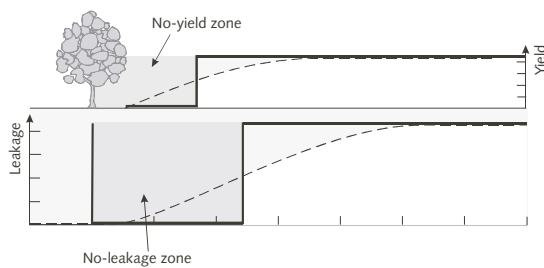
Land managers considering planting tree belts would like reliable predictions of both the benefits the trees can provide and the likely loss of crop or pasture production, but these are impossible to make accurately for the wide range of soils, climates and tree species found across Australia. Researchers have devised a useful means of determining whether planting trees in belts or in woodlots should be the best option in a particular situation. The method is aimed at recharge areas of a catchment, where the watertable is deep and trees are rain-fed only.

Because the tree roots spread into the surrounding soil, a tree belt will prevent or restrict leakage to groundwater over an area greater than that occupied by the trees. A simple way to predict the size of the net ‘no-leakage’ zone involves comparing the belt’s leaf area index (LAI) with an estimate of the LAI of the area’s original vegetation. A strong relationship exists between climate and the LAI of the natural tree and shrub cover, making it possible to estimate the original LAI from average annual rainfall and evaporation.

The downside of increased recharge reduction is reduced growth of crops or pasture in the areas where the trees compete with them for the available moisture. Field experiments show crop or pasture yields rise from zero immediately adjacent to a tree belt to the open paddock level some distance away. Yield data from transects away from a tree belt can be used to estimate the size of the net ‘no-yield’ zone; as use of yield mapping grows such information will become increasingly available. The impact of trees on yield of crop/pasture varies depending on species and environmental conditions.



The method proposed for assessing whether tree belts or woodlots offer the best prospects on a site involves comparing the sizes of the no-leakage and no-yield zones. For example, calculations for wheat country near Esperance, WA, gave a no-leakage zone width of 32 m, compared with 18.6 m for the no-yield zone. As the ratio of these figures is greater than one, tree belts are the better option. A second example comes from a tagasaste alley crop experiment near Moora, WA. In this situation woodlots would be advisable, as the zone widths were 3 m for the no-leakage zone and 5 m for the no-yield zone (a ratio of less than one).



The no-yield and no-leakage zones linked to a tree belt. The slow increase in yield and leakage away from the belt is reduced to a step function to facilitate easy comparison of the above- and below-ground effects.

Year-to-year rainfall variability presents the greatest challenge to the integration of trees and crops. The area of trees needed to prevent leakage to groundwater in an average year can be calculated, but this will allow some leakage in wetter years. In dry years, competition by the trees for the available moisture may be so great that no crop can be grown.

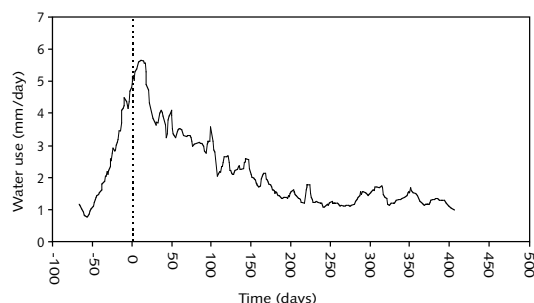
This means agroforestry in which trees are arranged in belts is more likely to succeed in higher rainfall regions than in lower-rainfall regions. Mixing trees and crops becomes more difficult in very low rainfall areas and as season-to-season variability increases.

Planting over shallow, saline watertables

Planting trees over shallow watertables is a practical way to reduce saline discharges in locations where the water is not too salty and lateral water movement prevents salt building up in the soil. However, in the much more common situations where aquifer systems are large and saline, salt accumulation will make such plantings unsustainable. In most cases, tree planting in discharge areas cannot be seen as a substitute for planting in recharge areas.

Planting trees over shallow watertables — on land likely to be subject to periodic waterlogging and rising salt levels — has obvious appeal. By using the groundwater, plantations could be expected to help prevent damaging discharge.

The main difficulty with this strategy is that salt will probably build up in the root zone; most of the salt in water taken up by trees is left behind in the soil. Growth rates will slow as the salt accumulates, and eventually even salt-tolerant trees may die.



Daily water use by *E. camaldulensis* from a watertable 93 cm below the soil surface. Prior to day 0 the watertable was fresh. After that, the watertable was slightly saline (conductivity = 2 000 EC).

Nevertheless, growing trees over shallow, saline watertables can be a practical proposition in some situations. Research has identified the conditions that should lead to a good outcome.

Trees take up groundwater mainly from the capillary fringe, the layer of wet soil immediately above the watertable. The initial depth of the watertable, soil texture and salinity are critical in determining the survival prospects of plantations. Very shallow watertables — within a depth of about 1.5 metres — present a particular problem because water evaporates from the soil surface,

leaving behind a salt crust. Trees can help by intercepting water as it moves towards the surface, but then the salt is left behind in the root zone.

The following scenarios provide an indication of how plantations might perform in catchments with a range of hydrological characteristics:

- *The watertable depth stays constant because additions from surrounding recharge areas replace groundwater taken up by the trees.* In this scenario, all the salt left behind stays in the soil from which water is extracted. How long trees can survive will depend on the depth of this soil zone, what salt concentration the trees can withstand, the salinity of the groundwater and the trees' transpiration rate. Different assumptions result in salt levels reaching a threshold figure, above which tree growth stops, within just 3.5 to 14 years.
- *The watertable level falls in response to water use by trees.* A plantation monitored in Victoria for 20 years lowered the watertable from 1 to 5 metres depth. However, groundwater use appeared to decline dramatically after the first ten years and leaf area and water use decreased significantly indicating the plantation is unsustainable. The salinity of the watertable is in the range 3000–5000 EC (aquatic ecologists consider 5000 EC the divide between fresh and saline water). Modelling studies indicate that, where accumulated salt cannot be 'exported' from a site, tree plantations grown over groundwater with a relatively low salinity of 3000 EC or above must generally be considered unsustainable. Also, if the trees are replaced by pasture, growth may be harmed as the watertable rises again, bringing salt with it.
- *The watertable level falls and salt is carried out of the root zone by lateral water movement.* At an experimental site in Western Australia with a thin, transmissive aquifer and relatively low groundwater salinity, the land area affected by salinity decreased substantially and rapidly even though only 2% of the catchment was planted with trees. Unfortunately, such 'best case' conditions are not often found in Australia.

Plantings over shallow aquifers should be designed using estimates of the saturated conductivity of the soil and expected groundwater extraction rates. It is essential to plan for, and monitor, salt build-up in the root zone and its likely impacts on tree water use and survival.



The research suggests tree planting can have a major impact in reducing the area of saline discharge where aquifers are relatively shallow, the water is not too salty, and lateral water movement prevents salt accumulation. However, prospects are not nearly as good in the much more common situations where aquifer systems are large and saline. In most cases, tree planting in discharge areas cannot be regarded as a substitute for planting in recharge areas. At best, the strategies are complementary.

Species selection and farm forest management

Information compiled on the suitability of 32 species for different rainfall and temperature zones, along with their tolerance of frost, salinity, acidity, alkalinity and waterlogging, will assist the choice of trees to plant. As well as choice of appropriate species, and the best seed source within species, good management is vital to the success of tree planting for salinity control.

Choosing species suited to the particular climate and site conditions and appropriate management practices are essential to realising the potential benefits of tree planting for salinity control.

Important considerations for species selection include:

- *Climate.* Annual rainfall and its variability, temperature — especially the extremes experienced — and the frequency and severity of frosts are the key variables.
- *Soil conditions.* Soil texture and structure, water infiltration rates and water availability, and soil chemical conditions — nutrient status and acidity, salinity, alkalinity and sodicity — influence root and foliage growth.
- *Watertable depth and salinity.* Tree species show a range of responses to these key variables.
- *Commercial opportunities.* Wood products, non-wood products such as eucalyptus oil, and carbon credits provide various income opportunities.
- *Potential competition with crops and pastures.* This can be an issue when trees are grown in designs other than plantations and woodlots.

The survival and growth of trees depend on a myriad of factors, and species performance for particular sites — especially on saline land — often cannot be predicted with precision. Nevertheless, much information is now available, and the suitability of 32 species for different rainfall and temperature zones has been summarised in the book, along with their tolerance of frost, salinity, acidity, alkalinity and waterlogging.

For example, in an area with 850 mm average annual rainfall, a mean temperature of 15°C, no salinity or waterlogging, neutral pH and low frost risk, the choice of species will be wide and the market for tree products may strongly influence the decision. However, a site with 500 mm rainfall, an average temperature of 20°C and few frosts, but high salinity and seasonal waterlogging, presents far fewer options; few species have high tolerance of salt and waterlogging. The most suitable species appear to be river cooba (*Acacia stenophylla*), old man saltbush (*Atriplex nummularia*) and swamp she-oak (*Casuarina obesa*).

Most tree species currently of commercial value have only slight to moderate salt tolerance. Species with moderate high salt tolerance, such as river red gum (*Eucalyptus camaldulensis*), show more growth decline as root-zone salinity increases than species with high salt tolerance, such as swamp yate (*E. occidentalis*). Other species with a strong capacity to survive and continue to grow and use water in the face of increasing root-zone salinity include river cooba and salt paperbark (*Melaleuca balmaturoorum*).

As well as choosing appropriate species, growers should ensure the trees they plant are from the best provenance (seed source) within a species. Growth rates and traits such as stem form can vary markedly between provenances. Trials on saline sites have shown, for example, that the best-performing river red gums come from north-western Victoria.

In general, commercial opportunities for farm forestry are more restricted in low rainfall zones than in wetter areas, so appropriate species selection is vital. Options that may be available include production of eucalyptus oil from mallees, sawn timber from some eucalypt species, and biomass feedstock for production of bioenergy.

Tree management factors most likely to influence stand growth and water uptake are site preparation, fertiliser use, weed control and planting density. Thinning and pruning may also be necessary if an aim is to produce high quality timber or to reduce the risk of drought-induced tree death. Relatively low tree stocking densities tend to be most cost-effective when the primary aim is to maximise water use. On lower rainfall sites, densities around 200–500 stems per ha are likely to be suitable.

Suitability for climatic and soil conditions of selected tree and shrub species currently planted or potentially suited to farm forestry and dryland salinity management in southern Australia¹.

	Mean annual rainfall (mm)				Mean annual temperature (°C)				Frost	Salinity	Acidity	Alkalinity	Water logging
	<400	400–600	600–800	>800	>23	17–22	12–16	<12					
<i>Acacia dealbata</i>		**	**	***			***	**	***	*	**	*	*
<i>A. mearnsii</i>			***	**		**	***	*	**	*	**	*	*
<i>A. melanoxylon</i>			**	***		*	***	***	**	*	**	*	*
<i>A. saligna</i>		**	***	*		***	***		*	***	*	**	*
<i>A. stenophylla</i>	*	***	**		***	***	***		*	****	*	**	***
<i>Atriplex nummularia</i>	***	***				***	**		*	****	*	**	*
<i>Casuarina cunninghamiana</i>		***	***	***	**	***	***		*	**	**	*	**
<i>C. glauca</i>			**	***	*	***	***		*	***	**	*	***
<i>C. obesa</i>	*	***	***	*		***	***		*	****	*	***	**
<i>Chamaecytisus palmensis</i>		***	**			**	***		*	*	*	*	*
<i>Corymbia maculata</i>		*	***	***		***	**		*	*	**	*	*
<i>Cupressus macrocarpa</i>		**	***	*		***	***		**	*	**	*	*
<i>Eucalyptus camaldulensis</i> (northern)	***	***	***	***	***	***			*	**	**	**	***
<i>E. camaldulensis</i> (southern)	***	***	***	***		***	***		**	**	**	**	***
<i>E. cladocalyx</i>	*	***	**			***	***		*	*	*	**	*
<i>E. globulus</i>			**	***		***	***	**	**	*	**	*	*
<i>E. grandis</i>				***	**	***	**		**	*	**	*	*
<i>E. largiflorens</i>	**	***	*			***	***		*	**	**	**	**
<i>E. leucoxydon</i>	*	***	***	*		**	***		**	**	**	**	*
<i>E. nitens</i>			**	***		*	***	***	***	*	**	*	*
<i>E. occidentalis</i>	*	***	***		***	***			*	***	*	**	***
<i>E. polybractea</i>	*	***	**		***	***			*	**	*	*	*
<i>E. robusta</i>			*	***		***	**		*	**	**	*	**
<i>E. sideroxylon/tricarpa</i>	*	***	***	*		***	*	*	**	*	**	*	*
<i>E. spathulata</i>	**	***	**		***	***			*	****	*	*	**
<i>E. viminalis</i>			**	***	*	***	**	***	*	*	**	*	*
<i>Grevillea robusta</i>			**	***	***	**	**	**	*	*	**	*	*
<i>Melaleuca balmatrorum</i>	**	***	***		**	***			**	****	**	**	***
<i>M. uncinata</i>	**	***			*	***			*	**	*	**	*
<i>Pinus pinaster</i>	*	***	***	**		**	***	*	**	**	**	*	*
<i>P. radiata</i>			**	***	*	***	**	***	**	**	**	*	*
<i>Populus deltoides</i>		*	***	***	***	***	***		*	*	*	*	**

Average annual rainfall: * = reasonable suitable; ** = suitable; *** = very suitable. The ratings do not imply a particular growth rate; they merely provide a comparison between species of relative performance within zones. In general, there is a positive correlation between growth and rainfall. Species rated as very suitable in low rainfall zones will have slower growth rates when grown at low rainfall sites than species rated as very suitable for high rainfall zones grown at high rainfall sites. For example, *P. pinaster* grown at a site with 500 mm annual rainfall will not grow as fast as *P. radiata* grown at a site with >800 mm rainfall.

Annual annual temperature: * = reasonable suitable; ** = suitable; *** = very suitable

Frost: * = can be planted in low frost-risk areas (<5 frost days per year); ** = can be planted in moderate frost risk areas (5–20 frost days); *** = can be planted in high frost risk areas (>20 frost days with minimum temperatures ranging between –5 and –10 °C

Salinity ²: defined here in terms of the electrical conductivity of a saturated soil paste (EC_e) in units of decisiemens per metre (dS/m) as an average over the root zone: * = slight (2–4); ** = moderate (4–8); *** = severe (8–16); **** = extreme (>16)

Acidity ²: * = pH 6–7; ** = pH 5–6; *** = pH <5

Alkalinity ²: * = pH 7–8; ** = pH 8–9; *** = pH >9

Waterlogging ²: * = days; ** = periodically (days to weeks); *** = seasonally (several weeks).

¹ Data compiled from various published, unpublished and personal communication sources. For a number of species, there is likely to be considerable variation between seed sources in response to climate and soil factors. Readers should consult local information sources.

² Ratings given for each species indicate that this average root-zone condition should not reduce growth markedly from optimal conditions, however combined stresses may have greater impact.

Site preparation may involve removing existing living and dead vegetation, ripping, mounding, and construction of vermin-proof fences. Addition of fertiliser will often be worthwhile, but sites where improved pasture has been grown may not benefit as nutrients are likely to be in good supply there already. Weed control, initially through a combination of knock-down and residual herbicides, is essential for maximising tree growth. Plastic tree guards can help suppress weed growth around trees and are likely to be particularly beneficial in tree belts.



Glossary

Aquifer: A saturated permeable geological structure that can transmit significant quantities of water under gravity

Capillary fringe: the region of soil just above the watertable where the soil pores are saturated but the fluid pressure is less than atmospheric (ie: the pore water is held under some degree of tension by neighbouring soil particles).

Discharge: Water flowing out of an aquifer (aquifer discharge), catchment (catchment discharge), or from groundwater through the soil surface (groundwater discharge).

Hydraulic conductivity: The ratio of the rate at which water can flow through soil to the pressure gradient driving the flow.

Leakage: Water that drains past the plant root zone; also called deep drainage.

Leaf area index: The ratio of the leaf area of vegetation to the land area covered.

Phase-farming: Alternating farming land uses — such as trees and crops.

Recharge: Accession of water to an aquifer system.

Saturated hydraulic conductivity: Hydraulic conductivity of saturated soil.

Unsaturated soil: The soil profile above the watertable and capillary fringe.

Watertable: The boundary between unsaturated and saturated soil, at which the pore water pressure is exactly atmospheric.

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