1-10-1998

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Recommended Citation

McConnell, C E. (1998), *Revegetation strategies for groundwater control in the eastern wheatbelt*. Department of Primary Industries and Regional Development, Western Australia, Perth. Report 186.

ISSN 0729-3135
October 1998

Revegetation Strategies for Groundwater Control in the Eastern Wheatbelt

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Resource Management Technical Report No. 186

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Contents

Introduction

Salinity is acknowledged as a major problem through out the wheatbelt of Western Australia, George et al 1997. Most salinity has developed as a result of rising groundwater levels at both a catchment and localized scale. Groundwater levels have risen due to an increase in the amount of water draining through the soil into the groundwater, i.e. there has been an increase in the amount of recharge. The replacement of long lived, deep rooted, perennial vegetation with short lived, shallow rooted, annual crops has caused the increase in recharge.

To tackle this issue many Catchment groups have undertaken farm planning to address a range of management issues. Options for salinity management are limited in low rainfall areas. They comprise: maximizing crop growth, surface water control, protection of remnants, site specific tree plantings and broadscale alley farming. Alley farming has been promoted for a variety of benefits, including increased water use. However, there has been limited hydrologic assessment of this management option and there are several concerns.

It has been suggested that trees have relatively localised affects on soil water and water tables, and will not have impact on a wide area, Barrett-Lennard (unpub). There is also a concern that in the process of using water, trees will concentrate salts in the root zone, eventually making conditions unsuitable for growth (Thorburn 1996). Schofield and Scott (1991) found at Boundain, a tree trial planted with the aim of reducing groundwater levels, that there was an increase in soil salt levels under trees. Whilst Bell et al (1990) refer to similar evidence they suggest that it may be a function of a low rainfall environment (<500mm). Potentially these concerns may limit water use of alleys and their effectiveness in groundwater control.

Study Area

A study area was chosen within the Pindar Tardun catchment, (a Focus Catchment Group set up under the Salinity Action Plan, Figure 1) to investigate the potential of alley systems. This catchment is in the low rainfall zone of the wheatbelt, with typical annual rainfall ranging from 305mm at Tardun, to 338mm at Mullewa (west of Pindar). Soils are generally shallow, (1-5m) and underlain by the granitic basement of the Yilgarn Craton.

Due to the shallowness of the upper catchment soils, geologic features such as dolerite dykes are very evident both on ground and on the aerial photography. These highlight the complexity of the geology that will impact ground water movement through the catchment.

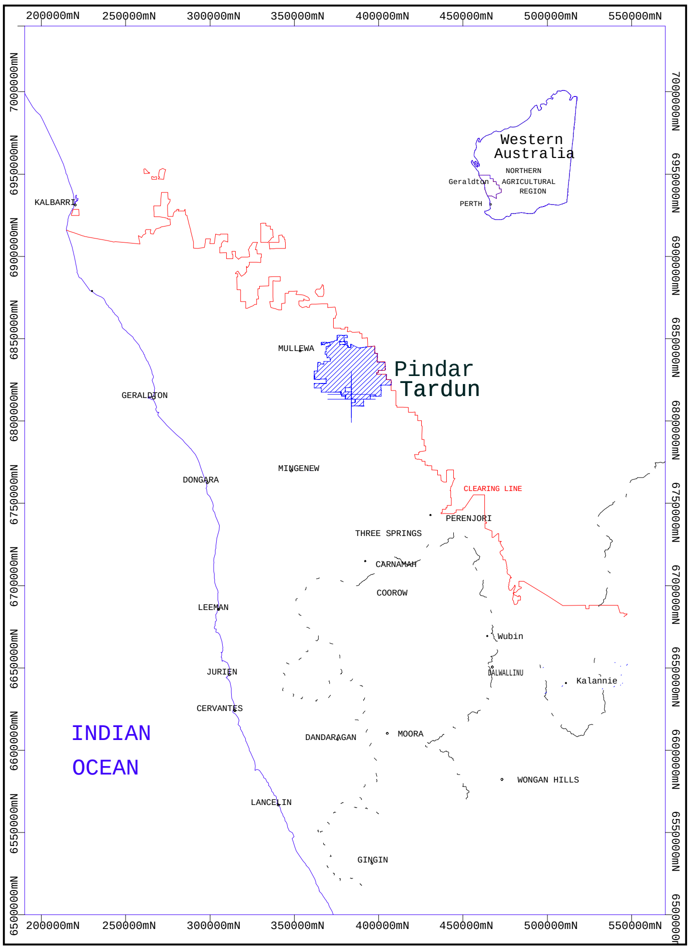

Figure 1. Location of Pindar Tardin Focus Catchment.

In 1995 around 10% of the catchment was reported to be affected by salinity (Clarke 1995). Since the report was compiled anecdotal evidence from farmers has suggested that salinity has spread. The main areas of spread surround the salt affected drainage zones of the valley floors.

Salinity management in Pindar-Tardun has included:
- changes in cropping rotations to include higher water use crops such as lupins
- increased water use efficiency of crops, (possibly increasing water use),
- management of surface water to prevent ponding and recharge, and
- increased number of perennials in the farm system, both woody and herbaceous.
- engineering options such as pumping and deep drainage have been discussed.

Most of these options have been applied at a localised scale. However, adoption of better crop rotations has been across the catchment.

Many examples from the eastern areas of Australia have concluded that the only effective management of salinity is on a catchment scale, (Greiner 1997, Reid 1995).

One option for Pindar Tardun to increase management to a catchment scale was the inclusion of perennials over a larger portion of the catchment.

In the past, perennials were incorporated into farming systems as a site-specific option, e.g. around discharge areas and sandplain seeps, and broadly in the form of remnants. However, alley farming, which incorporates areas of crop separated by rows of trees, has been developed as a compromise between native systems and broadscale cropping. The alley-farming concept holds promise however there is little solid data to suggest that this is an effective management strategy for groundwater control.

Boundain, (near Narrogin) is the only site in Western Australia with documented, long-term records that show the impacts of an alley set up. It has been monitored from 1980 until present. The data showed no significant change in piezometric levels in the first ten years, however since 1990 piezometric levels have fallen. The lowering of water levels has been attributed to trees, (Stolte et al 1996).

To increase the understanding of alley systems, the concept was investigated at Pindar Tardun to determine if alleys could control groundwater, and, if so, how much of the catchment area might need to be planted to perennials.

Investigating the hydrologic aspects of the catchment was difficult given the limited amount of environmental data available. This is frequently the case for farmers and so data was used from any relevant sites in the immediate area and from other sites in low rainfall zones. These included the Canna catchment, located directly south of Pindar-Tardun. Given the closeness of location and similarities in soils, data from this catchment was used to enhance the study at Pindar-Tardun. A water balance technique was used to examine the importance of different aspects of the hydrologic cycle.

Rainfall

Average annual rainfall in the region typically varied from 305mm at Tardun, to 338mm at Mullewa, and 364mm at Canna. Initial inspection of bore data from Canna suggested that the biggest rise in water tables related to above average rainfall events. When rainfall was close to average groundwater levels only rose a small amount, implying that in an average year evaporation, crop growth and perennial vegetation used most of the rainfall. However, in the wetter year, the transpiration of crops and perennials was not sufficient to use all the water and ground water tables rose significantly.

Actual data from a bore in the Canna area is shown in Figure 2. This shows that for the period between 1994 and early 1996 there was very little change in groundwater levels, however, the wet winter of 1996 had an extreme impact. Rainfall for the 1996 growing season was 389mm (Canna), over 100mm greater than average growing season rainfall of 284mm. This excessive rainfall produced a jump in the hydrograph of over 1m in this and other bores in this catchment. Water levels drained off over the summer but have not returned to previous levels.

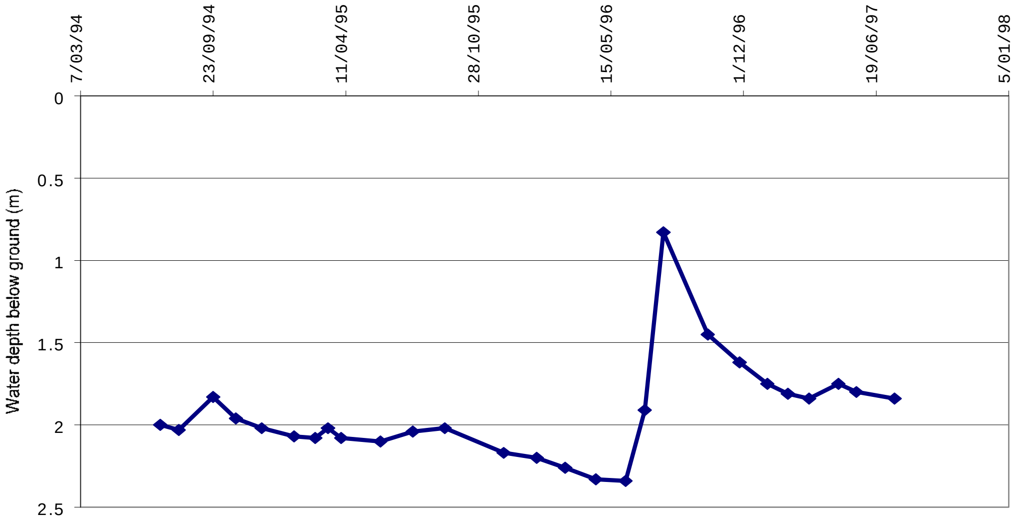

Figure 2. Canna Catchment bore OM11. Hydrograph (Data from Speed & Simons, unpub.

The rainfall records from Canna extend back for 80 years and were used to analyse how often a wet growing season occurred (i.e. one that was at least 50mm greater than average). The data showed that a wet growing season occurred one year in six. Figure 3 shows just the last 26 years of the data record, each year displayed from November to November. It illustrates how frequently and consistently both growing season rainfall and summer rainfall exceeds the average. These excesses may contribute to recharge.

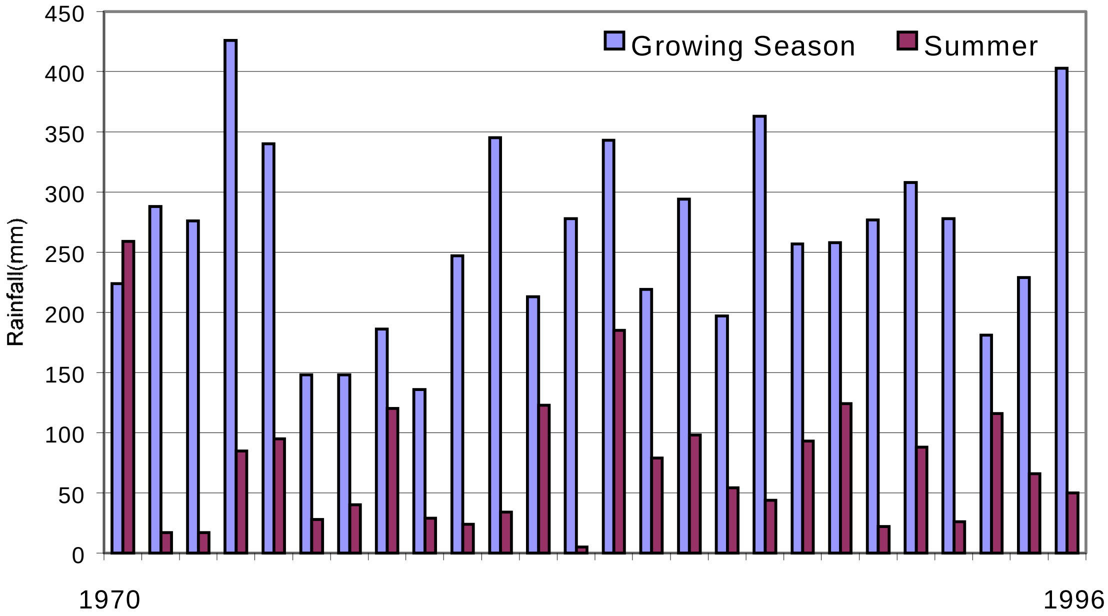

Figure 3. Yearly summer and growing season rainfall for Canna, 1970 – 1996. Average Growing Season rainfall = 284mm, Average Summer rainfall =80mm.

The impact of summer rainfall as episodic events can also be significant. Long-term records suggest that summer rainfall averaged up to one third of the annual rainfall. This also can have significant effects on the water table. Figure 4 is a hydrograph of bore data from Merredin, (another low rainfall wheatbelt location). The site is in a mid catchment location and demonstrates the impact of one summer thunderstorm. In this instance the recharge that resulted took nearly two years to drain away from the site.

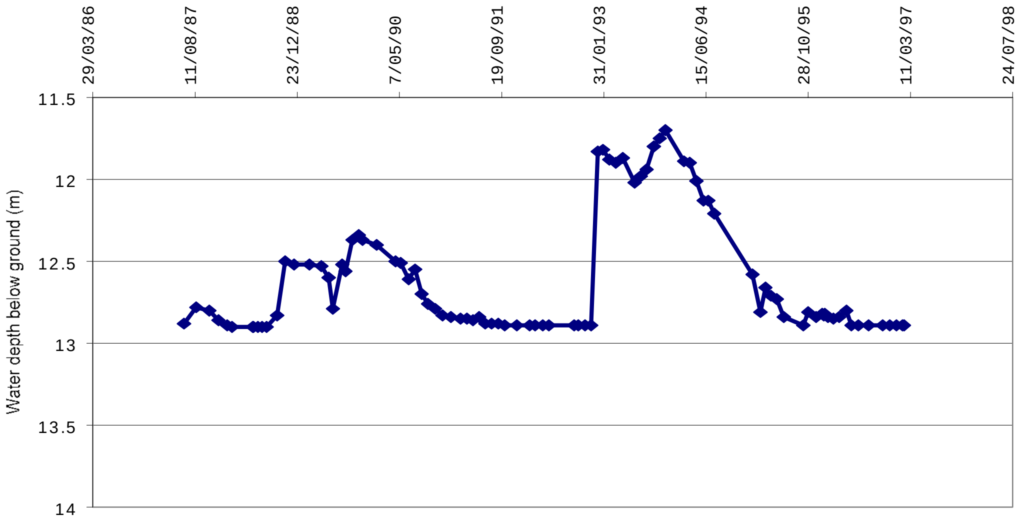

Figure 4. Merredin Catchment Bore MDB. Hydrograph

Water Balance.

The significance of this data to recharge was addressed by using the Canna rainfall data to drive a simple water balance calculation. The water balance was as follows –

P = Ro + Et + D + E Equation 1

Where P = Precipitation, Ro = Run off, Et = Evapotranspiration, D = deep drainage or recharge, and E = evaporation. Stored soil water was assumed to have no net change on an annual basis.

Precipitation was taken from the actual rainfall records. Et was the evapotranspiration of crops. A literature review of crop Et for the less than 400mm rainfall zone suggested that crop Et could be estimated as approximately two thirds of annual rainfall. Runoff was assumed to be 10% of rainfall, (this might be high, although given the shallow soil profile, not unreasonable.) Evaporation was seen as important during the summer period and was set as 90% of the summer rainfall component. Using such high summer evaporation gives a bias toward wet growing seasons. This was used to emphasize that growing season rainfall should not be underestimated. Results from water balance calculations for an average year and 1996, (very wet growing season), are shown below.

Year	**Growing Season Rainfall (mm)**	**Summer Rainfall (mm)**	**Total Rainfall (mm)**	**Estimate of Crop Et (mm)**	**Runoff (10%) rainfall (mm)**	**Summer Evap (90% of summer) (mm)**	**Recharge (mm)**
Average	243	82	325	214.5	32.5	73.8	4.2
1996	389	68	457	301.6	45.7	61.2	48.5

Table 1. Water balance calculations for an average and wet year in the Canna region.

This water balance calculation was the basis for estimating recharge for all years of rainfall data in order to determine the significance of rainfall events. The results from this extended analysis are shown in Table 2. They are divided into groups based on increasing amounts of recharge. For each recharge category total rainfall, growing season rainfall, summer rainfall and occurrence was calculated.

Recharge (mm)	**Total Average Rainfall (mm)**	**Average GS rainfall (mm)**	**Average Sum rainfall (mm)**	**Occurrence (% years)**
0	417	269	148	**29**
10	254	198	56	10
20	363	287	76	13
>20	355	312	43	**49**

Table 2. Analysis of Canna Rainfall (1917 – 1996) data categorized by amounts of recharge.

The data demonstrated the differences between the average year, where there is no or little recharge (0mm) and the wet growing season and/or summer rainfall events, where there is significant recharge, (i.e. >20mm). Interestingly these two categories dominate rainfall/recharge patterns in this area.

The assumption that 90% of summer rainfall evaporates or runs off, (hence only 10% is available as recharge), may underestimate summer recharge but it has demonstrated the importance of growing season rainfall in this region. The analysis suggested that episodic events were the significant contributors to recharge. The impact of episodic events was tested by plotting a hydrograph (based on cumulative recharge), derived from a rainfall driven water balance. Three specific yields were used to represent different soil types. This produced a graph, (Figure 5) somewhat similar to the real data from Canna, (Figure 2). It showed that episodic events are by far the most important in terms of recharge and groundwater rise. This has major implications for management, as these types of events are less frequent and far harder to control.

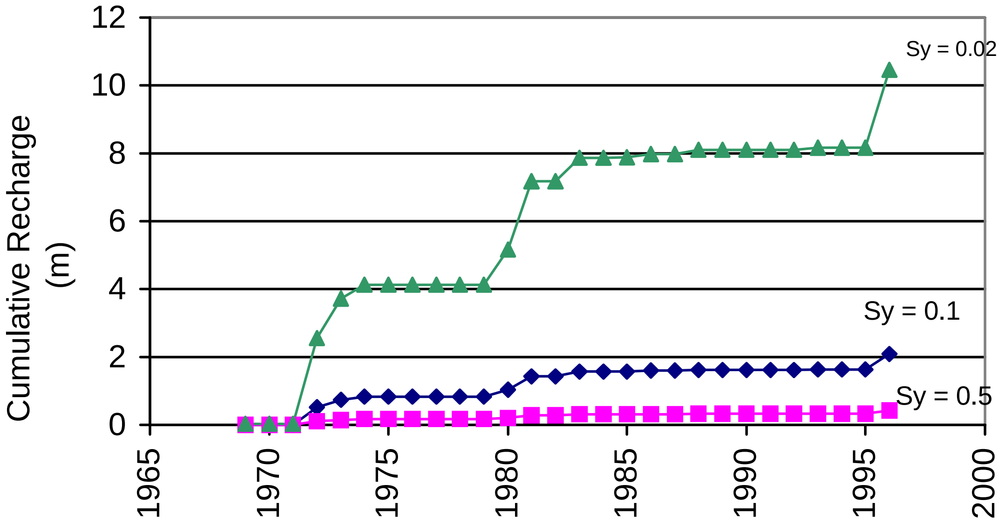

Figure 5. Estimated groundwater rise from water balance calculations.
The modeling shows a pattern where groundwater levels rise in response to an episodic event and then 'sit' during a period of average rainfall.

This analysis was significant because it highlights the importance of non-average years. A number of studies, e.g. Hamilton & Bathgate (1996), consider only the average year in calculating water balances, and from this determine management. The management suggested by Hamilton & Bathgate, (1996) was based on increasing tree numbers in the landscape. However, using the average year, the number of trees required to "soak up" the recharge is relatively few compared to what is required in a wet year. Given the importance of episodic recharge, (Figures 2 & 5), use of average rainfall will underestimate amounts of perennial vegetation required to restore a balance in the hydrologic system.

Plant Water Use.

Increasing the water use of plants (usually by variety and number of plants) can also reduce recharge. Whilst this is theoretically simple, is a much harder concept to apply.

The concept of using perennials (trees) is based on their ability to use more water than annuals. In an alley system perennials can have three possible impacts – 1) they can use no more water than annuals and have no impact, 2) they can use a volume of water equal or less than that of rainfall (but more than annuals), thereby reducing the overall amount of recharge. In this scenario groundwater levels may continue to rise but the rate of rise will be less. Or 3) they can use more water than falls as rainfall, drawing the excess amount from groundwater sources and/or stored soil moisture. This has the potential to lower groundwater levels.

The latter is the aim of alleys where salinity amelioration is intended. The annual crop zone under utilizes rainfall. This excess moves laterally through the landscape to the tree zone where it is used by perennial trees. Theoretically, the net result is to maintain groundwater levels over an annual cycle.

However, there are a few factors that prevent perennials from using all the water theoretically available.

1. Roots need to be able to access groundwater
2. Water movement from the crop zone to the perennial zone must be sufficiently quick to allow perennial uptake before the next volume of water enters the groundwater system. The rate of water movement will be limited by the physical attributes of the soil and slope/topography of the landscape.
3. Water must be of suitable quality for plant use
4. Plants must be healthy and unstressed to facilitate maximum water use.

These factors must all be satisfied to achieve maximum water use/Et of the plants.

To investigate the number of perennials required to utilize the excess recharge, these factors were assumed true. Plant Et estimates were obtained from the literature. These were used with the rainfall analysis to determine the amount of vegetation required to satisfy the water balance, such that there was no recharge.

To do this some further assumptions were made. These included
The amount of water used by individual perennial plants was not affected by density. (This will be true until the density is such that leaf area per plant is reduced by competition).
That soil type has no influence on water uptake.

Equation 1 was used to estimate the volume of recharge created under a cropping situation. A range of perennial plant Et estimates are available. Table 3 illustrates a range of measured tree Et figures. An average tree Et figure of 10m3/yr/tree was used for ease of calculations.

Tree Species	**Evapotranspiration (m^3/stem/yr)**	**Author**
E.salmonophloia	3 – 15	Farrington et al 1994
E.salmonophloia	18.25	Farrington et al 1994
E. cladocalyx	9.5	George 1991
E. camaldulensis	8	George 1991
E. wandoo	18.25	Hobbs
3yr Euc on seep	10	Hobbs

Table 3. Estimates of tree evapotranspiration (m^3/stem/yr)

Recharge Vol (mm)	**Recharge Vol (m3/ha)**	**No of trees required/ha**
0	0	0
10	100	10
20	200	20
50	500	50

Table 4. Theoretical number of trees required to use recharge water. (no consideration has been given to the physical constraints on water movement).

The number of trees required to simply utilize the recharge created by one hectare of crop was calculated and presented in Table 4. In an average year where recharge is negligible, no trees are required. However, during wet winters or episodic summer events the number of trees required varied from 10 to 50, depending on the volume of recharge. Given that these events have been demonstrated to be the main causes of groundwater rises, management must be based on these higher levels of recharge. No consideration has been given to water quality, depth or tree health in these calculations. Should any of these be less than optimum, tree Et will be less, and hence more trees would be required to utilize the water.

Groundwater Movement

In a theoretical context it is easy to balance the number of trees to the amount of recharge created by a given area of annual crop. However, as mentioned a limiting factor is the rate of lateral movement of water through the landscape. The movement of groundwater through soils in Western Australia is very slow.

George, (1992) estimates hydraulic conductivity's in the order of 0.5m/day in sediments and 0.065m/day in deeply weathered profiles.

The velocity of lateral flow or the movement of water through the soil can be estimated using Darcy's equation for discharge of water through a soil medium. This equation states that velocity (v) is proportional to:

- the hydraulic head of water (i.e. the difference in height of water), (dh), and inversely proportional to the flow length (dl)
- and the Hydraulic conductivity, (K)

This is represented by the equation: $v = K (dh/dl)$ Equation 2

These attributes are difficult to obtain without detailed investigation. The Geological Survey of Western Australia have done some investigations in the catchment directly west of the Pindar area and state that the 'groundwater flow systems are dominated by topography,' (GSWA undated). The gradient of groundwater flow (dh/dl) can therefore be estimated if it is assumed that groundwater gradients are roughly equivalent to surface gradients. Several transects within Pindar-Tardun were measured to accurately estimate slope.

Hydraulic conductivity was estimated using data from several bore sites within the Canna catchment, drilled by Speed and Simons, (unpub). None were tested for hydraulic conductivity. However, detailed drill logs were available and could be used to give an indication of soil profiles. George, (1992) listed a range of K values for saprolite and for deeply weathered soils from the Eastern Wheatbelt. Descriptions were consistent with those at Canna, and this data was used to estimate hydraulic conductivity.

The range of physical characteristics for the soil types in Pindar – Tardun were compiled in Table 5. Velocities were calculated using this data and Equation 2. The estimated velocities range from virtually 0 (clays) to 41m (sands) per year. However, for the majority of soil types, the velocity of flow in the saturated zone is minimal (<5m/year) in an annual time frame. This is an important consideration for groundwater management.

Table 5 shows that OM09, for example, had sandy clayey soils, with an estimated velocity of only 0.95m/yr. Therefore, any recharge moving through the soil landscape within the saturated zone, would move approximately one meter over a year period. This indicates that recharge water on ‘heavy’ soil types actually needs to be used where it falls, i.e. 100% of this landscape unit requires perennial cover. A tree perennial would obviously be unworkable, should the land be more valuable for cropping. Therefore other forms of perennial should be considered, e.g. perennial grasses or lucerne, possibly as a phase cropping scenario.

The situation is different for OM14 where there were lighter soils. Here the profile was made up of sands with high rates of groundwater movement. In this situation water can move up to 41m/year. The velocity figures can be used to indicate the maximum area that can be occupied by crop. That is, if water can move 40m/year then the area of crop can not be wider than 40m or else the excess recharge occurring beneath the crop can not move from the crop zone into a tree zone.

	Bore ID	**Depth of profile**	**Depth of saturated zone**	**Description of saturated profile**	**Estimate K Saturated zone (m/s)**	**Estimate of Slope**	**Estimate of velocity (m/yr)**
Brown Sandy Loam	OM10	6	2	Micaceous saprolite	1.00E-05	0.011	3.5
	OM09	5	1.5	qtz, clay and sand	1.00E-05	0.003	1.0
	OM07	9.6	5	saprolite, silcrete, coffee rock	1.00E-05	0.0009	0.3
Sand over Gravel					0.50E-04	0.011	17.3
York Gum					1.00E-05	0.011	3.5
Clays	OM06	5	2.5	gritty clays, coffee rock	1.00E-07	0.016	0.1
	OM16	5	3	Silcrete	1.00E-07	0.0006	0
Deep Yellow Sands	OM14	20	16	silcretes, clays sands	1.00E-05	0.013	4.1
Perched					1.00E-04	0.013	41.0
Gravelly Ridge					1.00E-05	0.02	6
Rocky soils	OM11	8	0.5	Kaolin	1.00E-05	0.01	3.2

Table 5. Summary of data used in calculations. Derived from Field data, Speed & Simons (unpub) and George (1992)

Discussion of results

The data analyzed has shown that if net groundwater levels are to remain constant (i.e. there will be seasonal fluctuation but no trends over a year to year period), and the physical attributes of soils are considered, then certain types of revegetation are required. That is, on most soil types common in the eastern wheatbelt, the movement of groundwater in the saturated zone is so slow, that it will build up vertically (i.e. rising water tables) quicker than it can laterally move downslope through the landscape. Therefore, revegetation options must be located where the recharge occurs, not somewhere else in the catchment. So most heavy soils require revegetation of some form to increase water use and reduce recharge.

The exception is for sands and gravels that have high rates of lateral groundwater movement. In these soil types it is quite feasible for an area of crop to create recharge and an area of trees located down gradient, to use up the excess water. The areas required can be calculated as follows:

Calculations to determine tree requirements and areas occupied by crop/ trees.

Input data

Velocity = 40m/yr
Crop Width = Velocity = 40m
Length of crop = 100m (this is an arbitrary figure)

Total area of crop
= 40 * 100
= 4000m^2

Recharge:
4.2mm/m^2 (average year) to 48.5mm/m^2 (wet year) [Table 1].
= (4.2*4000) to (48.5*4000) m^3
= 16.8 – 194 m^3 for total area

Number of trees:
Tree Et = 10m3/yr

Total number of trees
= 16.8/10 to 194/10
=2 to 20 trees.

Tree Area:

If assume that the standard planting layout of 5 x 5m,
Therefore the length between trees
=length/ No trees
=100/2 to 100/50
=50 to 5 m spacing, dependent on number of trees

Then minimum width of trees is 5m,

Proportion of areas as follows:

Crop 40m, 89% of area
Trees 5m, 11% of area

This shows that in sands where there is good lateral flow, approximately 11% of the area needs to be occupied by trees to utilize all of the recharge, (if all assumptions are met).

An estimate can be made of the perennial vegetation that might be required across the entire catchment to utilize recharge from cropping (and hence satisfy the water balance, minimizing recharge). Recharge figures used in conjunction with the areas of different soil types, (as above), were used to estimate the total area of the catchment that needed to be allocated to perennials, if recharge was to be totally controlled.

The total areas for each soil type were extracted from Clarke 1995 and area shown in Table 6. The percentage of area occupied by perennials calculated for each soil type. Given the physical parameters of this catchment it would require almost 55% of the area to be occupied by perennials if all of the recharge created by crops was to be used, Table 6. Note that the amount of perennial vegetation has been determined by the amount of each soil type. Catchments with a greater proportion of heavier soils will require a larger area of perennial vegetation to equalize the water balance.

Soil type	**% area in catchment**	**Estimated velocity (m/yr)**	**% area occupied by perennials**	**% catchment occupied by perennials**
Arable				
Deep Yellow Sands	11.2	41	11	1.21
Sands over gravels	31.4	3.5	23	7.2
Brown sandy loams	13.3	3	60	7.8
York Gum country	7.2	3.5	60	4.2
Red Sands	4.8	3	60	3
Wodgil sands	0.6	41	11	0.1
Gravel ridges	4.5	6	45	2.25
Grey clays	0.01	0	100	0.01
Saline flats	10.5	0	100	11
UnArable (rock)	16.4	-	-	16.4
Total	**99.9**			**53.2%**

Table 6. Percentage of catchment occupied by perennials needed to reduce recharge to zero.

Conclusions

This study has delineated a number of aspects related to management of groundwater for salinity.

These are:

- In the Pindar-Tardun Catchment, (and applicable to other low rainfall areas of the wheatbelt) significant recharge occurs during the wet growing season and during episodic summer events. The average rainfall year does not produce significant amounts of recharge.

- Management must consider the wet year (wet growing season and/or wet summer) and not just the average year.

- Successful groundwater management needs to consider both the volume of recharge and the velocity of groundwater flow.

- Saturated zones of most eastern wheatbelt soils have such low flow velocities that management needs to occur across the entire soil type to control recharge.

- Hydraulic properties of sands are such that alley farming may be feasible.

- Alley farming can be a feasible option under some soil physical conditions. These conditions are:
    - moderate hydraulic conductivities, ($>1 \times 10^{-5}$ m/s)
    - moderate groundwater gradients
    - groundwater is relatively fresh
    - perennial root systems can access the saturated zone.

- Within the Pindar-Tardun catchment approximately 65% of the area needs to be planted to trees in order to eliminate recharge created from cropping.

- Reducing the total amount of vegetation will increase the area of salinity, but the area of salinity may not be directly proportional to the area of vegetation.

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