Proc. Fourteenth Ann. Conf. Grassld. Soc. NSW, 1999, pp.66-72.

Pasture selection and management for water use

Geoffrey Beale

NSW Department of Land and Water Conservation
Centre For Natural Resources Research, Wagga Wagga NSW

Abstract. Dryland salinity is getting worse. Rising watertables contribute to land salinisation and declining water quality. The Murrumbidgee River currently carries the highest salt load in NSW, a large proportion of which is diverted to the irrigation areas. The water in some of the northern rivers may become undrinkable in the future unless something is done. Landscape elements behave differently, and pastures alone may not be sufficient to stabilise recharge and discharge. Groundwater recharge, salt wash-off and run-off and soil loss, require landscape-based solutions. Most of the salt entering streams is contributed by wash-off from the land surface including from saline areas. However, non-saline soils also contribute large amounts of salt to stream flow. Well managed pastures can help to slow accelerated recharge as well as reducing wash-off rates, but deep-rooted summer active species are more efficient in reducing recharge than summer-dormant cool-season species. Productive exotic C3 perennial pastures have a role in reducing wash-off on mid-slopes, lower slopes and drainage lines. Native perennial pastures are ideally adapted to the Australian climatic environment and, on shallow soils in rocky recharge areas, they are the only really viable management option in conjunction with trees.

Nearly 35 years ago, I asked my grandfather why he'd cleared so many trees from our family property at Tumut. He explained that it was to let the light into the pasture for photosynthesis. To an eight year old this was a good scientific reason. Back then a healthy pasture did not include trees. Today though, a healthy landscape and watershed needs summer active pasture and trees.

In southern Australia, large areas of once-productive land have turned saline over the past 10 years or so. In the Murray-Darling Basin, about 2,000 square kilometres of land have been affected. This area is expected to grow to 10,000 square kilometres by the year 2010. In NSW, more than 7,500 square kilometres will be affected by the year 2050. This alarming increase has stimulated interest and debate into how pastures use water, and whether pastures can be used to manage the water balance over the landscape.

Increasing pasture water use in the 500-600 mm rainfall zone would seem to be an attainable goal. However, if it were easily achieved, dryland salinity would not be the problem that it is. Water use by pastures is therefore a more complex issue than it seems. This paper examines the role of both pastures and trees in managing water in the landscape.

Dryland salinity and landscape health

In southern Australia evidence of salinity shows up as saline areas in the landscape, as well as in a general deterioration in stream and river water quality. Saline areas affect the productivity of individual paddocks. Salt patches may be of concern only to affected landholders, or they may be more widespread and become a local community problem. Saline discharge areas are usually some distance from the source of the recharge, and quite often the recharge area may be on a different property. This means that the landholder with the problem is often unable to solve it without going onto his neighbour's farm. So, tackling salinity as a group is often more effective than trying to do it alone, and salinity has become a major focus of landcare groups in southern NSW.

Areas of local discharge contribute saline runoff to creeks and rivers. This has an impact on water quality at a river-basin scale and is of national concern. Saline discharge from upland catchments is causing upward trends in stream salinities across the Murray-Darling Drainage Division (MDDD) (Jolly *et al.* 1997; Williamson *et al.* 1997). Analysis of stream flow and salt load records for rivers and streams in the NSW portion of the MDDD (Tuteja *et al.* 1999) indicate that surface wash-off, which includes shallow sub-surface flow, accounts for the majority of salt export from the landscape.

The highest absolute salt loads (tonnes) occur during periods of high rainfall. These also are associated with high river flows. The effect of wash-off on water quality is not immediately obvious because the salt is diluted and water quality appears to be high. For example, the Murrumbidgee river carries the highest salt loads in NSW, yet has the highest quality water of any of the major NSW river systems. Much of the water carried during high flows is ultimately diverted to irrigation areas. Here, the water evaporates, leaving the salts behind to accumulate or to be drained back into the river system. About 30 to 65% of the salt from the Murrumbidgeee river is diverted to irrigation areas.

An intensive study of the Kyeamba Valley east of Wagga Wagga (Tuteja *et al.* 1999) found that non-saline soils also contribute significant proportions of the total salt load reaching the stream. Saline areas are small and discrete and their runoff water contains high salt loads. However, non-saline soils occupy a much greater area. They contribute much more runoff which is less saline, but their overall contribution of salt may be just as great as that of saline areas. Wash-off includes shallow sub-surface water flow, and because nitrate also moves with the water, this may lead to nitrate leaching and soil acidification. Clearly, doing something about saline discharge areas and their specific recharge zones will only fix part of the basin-wide salinity problem.

Dryland salinity is caused mainly by increased deep drainage - the movement of water downward beyond the reach of plant roots. Deep drainage has increased because pasture uses less water than the original vegetation. Aquifers generally follow the shape of the topography and, as additional water is added, they fill to a greater height in the landscape. The weight of the extra water increases the pressure in the aquifer, causing water tables to rise, and seepage areas develop when watertables leak upward to the surface. If a well or bore were drilled into aquifers trapped under saline patches, the head of water may rise to several metres above the surface. So, there is usually a fair upward pressure driving seepage. When the seepage water evaporates, any salt contained in the water becomes concentrated at the surface. This causes the area to become saline.

Salt comes from other points in the landscape as well. Aquifers interact directly with streams. Streams occur at the lowest points in the landscape, and are often incised several metres into their flood plain. During dry periods when there is not much runoff, the main source of water entering streams leaks out of the landscape. Water entering the stream from aquifers is known as base flow. Base flow may in some cases be quite brackish and contain considerable quantities of salts dissolved in the ground water. Because base flow is not diluted during dry periods, low stream flows are associated with poor water quality. In southern NSW and Victoria, stream flows show marked seasonality, with low flows occurring mainly in summer when irrigation demand is highest.

Use of low-flow water for irrigation in the unregulated dryland catchments compounds the water quality problem. Salt in the water is stored on the irrigated land (or re-cycled through the soil profile) at times when water is scarce, and released as wash-off or through drainage when rainfall resumes and water use declines. As salt builds up in the landscape, the water quality of some unregulated streams may become too poor for irrigation.

The landscape - a factor to be reckoned with

Although deep drainage can occur anywhere in the landscape, it is more likely on rocky ridges and crests where soils are eroded, stony and shallow. Where deeper soil profiles with clay subsoils occur on valley side-slopes, surface wash-off (including sub-surface water movement) is more likely to occur, because subsoils are not highly permeable. Around the break of slope, where shallow soils meet the more weathered, clay-containing soil types, percolating water can move under the clay layer and be permanently out of reach of plant roots.

On valley floors and low-slope drainage lines where clay subsoils may be between 10 to greater than 40 metres in depth, deep drainage would be virtually impossible. Lightly textured soils, such as may occur in granite country, may present limited opportunities for deep percolation, but most often this would appear down-slope as sub-surface lateral flow which would not drain to water tables, but could still result in waterlogging.

In developing a strategy to combat dryland salinity, four landscape elements need to be recognised:

- The shallow-soil, stony ridges, which occur above the break of slope. These lands contribute most of the actual recharge.
- The mid-slope contributes most of the runoff and lateral flow that results in some wash-off.
- The lower slope receives most of the lateral flow where it may become runoff. This land contributes most of the wash-off.
- The valley floors and depressions contain the saline areas, and contribute salt as wash-off and base-flow to the streams and rivers.

Each landscape element presents a different set of processes and problems that need to be dealt with separately.

Yield, productivity and sustainability

Agricultural productivity is often gauged by the quantity of wool or numbers of steers or other products sold off farm. In other words, productivity and yield are thought of as the same thing. However, productivity and yield are **not** the same. Productivity measures the efficiency of production; yield measures how much is produced. Productivity is the ratio of inputs ($, labour, chemicals, expertise) to outputs (yield in some form). It there-fore measures how hard investment in the enter-prise works to produce the yield, not the yield itself.

Sustainability is also an efficiency measurement. It measures change in the production system (the paddock, the farm, or the river basin) through time and is usually expressed as a rate, for instance, the soil acidification rate, the soil erosion rate, rates of deep drainage and so on. By measuring rates of growth and decay, sustainability measures the health of the system itself - the ability of it to continue to produce.

Sustainability indicators have thresholds beyond which change becomes detrimental. For example, soils become too acid, waters become too saline, pastures become too weedy, or contain too few perennial grasses. This begs the question: how much damage can a production system sustain before it is damaged beyond repair?

Threats to sustainability show up as outputs of the production system. For instance, a saline seepage area at the bottom of a paddock is the product of climate, soils, geology, topography, vegetation, grazing and management all interacting. But it could be analysed and acted upon by breaking it down into inputs (are the investments right); the environment (has the climate changed); or the production processes (is the management right?).

Some factors affecting sustainability are predictable and stable *e.g.* it will always be generally hotter in summer than winter. Other factors are unstable and cannot be predicted (a bush fire, flood or heavy storm). Recharge is rainfall-driven and unpredictable. So long as the detrimental factors can be managed so they do not exceed threshold levels where outputs are reduced or permanent damage occurs, then production can be maintained within the bounds of sustainability.

If thresholds are exceeded, production becomes unsustainable and outputs will ultimately decline. In this case, the options are few - the cause must be removed, the production system must adapt to compensate, or it must be replaced by some other production system. Where the problem is caused by inputs of an unpredictable nature such as the weather, the probability of the event must be managed. This involves some sort of 'insurance'. For instance, recommended crop-planting dates aim for flowering to occur so there is less than a 10% chance of frost damage. The late frost last year was one of the 10% outside the probability envelope, and so was not covered by the insurance.

An example

In the following example, water use by an annual growing crop or pasture and a summer active perennial pasture (*e.g.* lucerne, Consol love-grass or a native pasture) have been compared for a 10-year period using data for the Kyeamba valley, east of Wagga Wagga using the WAVES model (Dawes and Short 1993). Figure 1 shows that for the period chosen, rainfall (the main input) was highly variable. This was reflected by differences in the outputs, which in this case were soil moisture, daily drainage rate, and leaf area (which is a measure of plant growth).

The differences between the annual crop or pasture and the summer-active perennial pasture were due to differences in how they "processed" or used the input (rainfall). In most years, soil under the summer-active pasture was drier than under the annual pasture/crop, but the difference did not seem large. However the summer-active pasture reduced the drainage rate considerably. This was because it maintained a high leaf area during summer and into autumn that allowed it to use water. The annual-growing pasture and crop accumulated water during summer and autumn, so it built up soil moisture reserves before winter, especially in wet summers and autumns. This reduced the capacity of the soil to take up additional moisture and deep drainage started earlier than for the summer-active pasture.

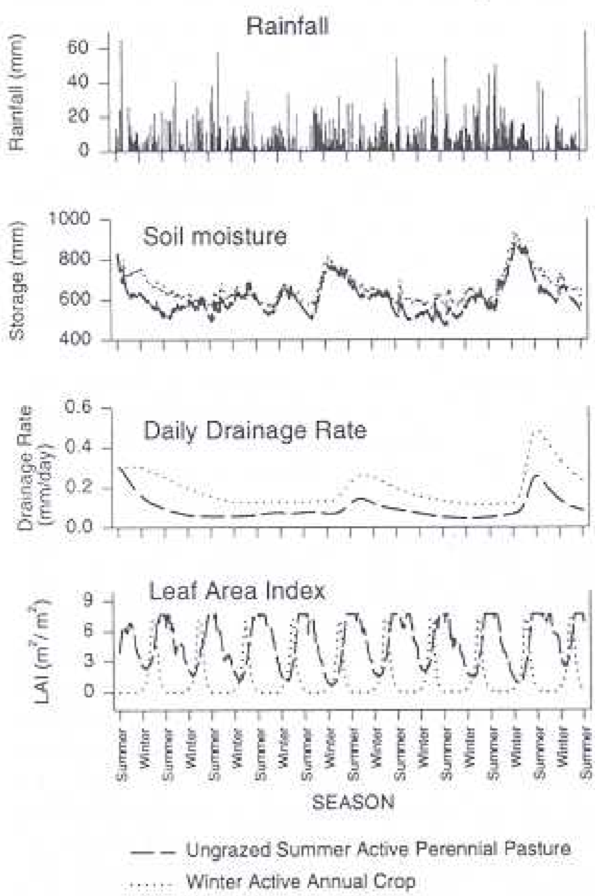

Figure 1. Simulated drainage rate, crop growth and soil moisture storage for two vegetation types using the WAVES model and historical rainfall at Wagga Wagga.

The simulation shows that the summer-active perennial pasture was better adapted to the unstable nature of the rainfall (the wet and dry years) than the annual system because its growth and water use was more consistent. In this example, the dryland salinity risk is affected by three factors:

- The timing and amount of rainfall
- The size and shape (depth) of the crop and pasture root systems.
- How long the vegetation stays green and over what season. (The potential for water use is greatest in summer)

Watertable recharge threshold levels

A certain amount of recharge is natural. In the Kyeamba Valley, an estimated additional annual average recharge rate of 20 to 30 mm/year has caused the water table to rise continuously for the last 50 years (Woolley 1991). Continuing recharge is a real threat to sustainability. The average difference between the annual pasture and crop and the summer active perennial pasture in the above example was about 37 mm/year. Although this is a simulated figure, it indicates that there is reasonable scope for summer active pastures to reduce recharge to somewhere near equilibrium levels.

The model predicts that if the valley were still covered by summer-active vegetation, there would be virtually no rise in watertables and no salinity - a highly sustainable system. Although there was some recharge risk for the summer-active perennial pasture during wet years, the recharge rate under the annual crop and pasture was high even during 'average' years. This production system is therefore not sustainable.

Pastures and trees - tools for managing water use

Pastures are the preferred vegetation community for grazing livestock. Pastures are dynamic ecosystems, containing a range of often competing sown and unsown species, which are continuously acted on by grazing animals, pests and disease, wild fauna, and the physical environment. In order to survive, pasture species need to be adapted to all the circumstances under which they grow. Rainfall, evaporation and temperature are major factors, as are soil characteristics, (depth, pH, fertility) and management.

The timing and amount of rainfall is particularly important. Only the bigger and less frequent rainfall events penetrate a normal soil to any great depth when the soil is dry. Thus, small falls of rain are usually only available to shallow-rooted species. The root systems of adapted deep-rooted species tend to shrink in diameter as plants run out of water. They are able to compete with shallow-rooted species for moisture by channelling rainfall down these shrinkage voids to where it can be stored for their use only. So rainfall does not only wet the soil from the top down, it can also wet from the bottom up!

The removal of deep-rooted vegetation, including trees, and its replacement with annual-behaving pastures and crops is the main cause of the water balance changes that have resulted in current salinity problems. This raises the question: are trees needed to reverse the salinity trends?

A study based on the Mona Vale catchment (Zhang *et al.* 1995; Zhang *et al.* 1998) within the Kyeamba Valley using TOPOG_IRM was used to investigate this question. About 55% of the 163 ha area was under improved pastures (mainly phalaris and subterranean clover). The remainder consisted of annual pasture and some small-block tree planting. Under normal management, the average annual leaf area index over the whole catchment in 1992, 1993 and 1994 was 0.37. Maximum values of around 1.5 were observed in spring.

Model simulations indicated that water use under the above systems would not arrest rising watertables. However, scenario modelling suggested that if approximately 30% of the catchment were planted to trees, watertables could be brought into equilibrium.

The Kyeamba Valley and Tarcutta Creek catchments are located adjacent to each other. Although different in shape and size, they are similar in soil landscapes, geology and rainfall. A comparison of in-stream salt loading from 1975 to 1995 using observed flows and electrical conductivity measurements (Tuteja *et al.* 1999) shows that the Kyeamba Valley is discharging approximately twice as much salt per square kilometre as Tarcutta Creek. A comparison of land use in the 2 catchments (Table 1) shows that trees occupy 6.2% of the area of the Kyeamba Valley, but about 31% of the Tarcutta Creek catchment.

This comparison supports the estimates of the modelling exercise. It shows that for existing pasture species and land use, trees need to be established over about 30% of the landscape in the Kyeamba Creek catchment in order to achieve equilibrium in the water balance. The trees do not have to be planted over every farm or paddock, but is clear that on land not suited to cropping, where summer-dormant annual or phalaris pastures are sown, trees are also needed.

Using pastures in the landscape

The three options available for using pastures to manage water use are:

- Sow pasture species that are well adapted to the particular landscape unit. Pastures should contain species that have a capacity to grow ac-

Table 1. Land use in the Kyeamba Valley and Tarcutta Creek catchments

Land use	Kyeamba Valley	Tarcutta Creek
	% of total area	
Pasture (native, naturalised or improved)	88.09	67.68
Crop (grain, fibre or fodder)	5.66	1.27
Horticulture	Nil	0.15
Trees (native)	6.20	17.43
Trees (Pine plantation)	Nil	13.40
Remainder (urban, quarry or water body)	0.05	0.07

tively during wet summers and which are able to control runoff and soil erosion.

- Manage existing pastures (including native pastures) so they remain persistent and productive, and maintain groundcover and accumulate green leaf in summer. Maintain and if possible increase the perennial component.
- Establish trees in grazed pastures.

In the southern half of NSW, the only commercially available, truly summer-active pasture species are lucerne and Consol lovegrass. There is a growing body of research evidence that shows that summer growth is vital if deep drainage is to be reduced (Beale 1993; Johnston *et al.* 1999). However, experiments have consistently shown that phalaris has only a limited capacity to reduce recharge, particularly if it is continuously heavily grazed and therefore unable to accumulate green leaf in summer.

Phalaris and lucerne lack persistence on less fertile sites, on acid soils and on steep, exposed landscapes. Cocksfoot and fescue also use water in summer, but cocksfoot is not deep rooted, and fescue only persists where rainfall is regular and reliable. Consol lovegrass needs to be sown in spring, which is difficult if pastures accumulate a large body of excess forage in spring. Excessive competition in spring can also reduce its persist-ence.

Therefore, there are no easy solutions for establishing and maintaining pastures which are capable of managing water use in the landscape. Development of better-adapted cultivars that are capable of summer growth should be seen as a high research priority.

A current DLWC project at Wagga Wagga is tackling the issue of productivity and water use by phalaris and native-grass based pastures at a small catchment scale. A low-input native grass pasture catchment is diverse and stable, but not highly productive in terms of carrying capacity (around 3 to 5 dse through the year). It contains a low frequency of weeds and many species are capable of summer growth.

A catchment sown to phalaris is more productive (5 to 10 dse through the year), but it contains a high frequency of weeds and few 'desirable' species capable of growth in summer. A survey of both catchments, in mid February found that the phalaris pasture was dominated by hairy panic (ranked 1st in 55% of measured quadrats) and heliotrope (ranked 1st in 16% of quadrats). Phalaris was only ranked 1st in 9% of quadrats. In the native grass catch-ment, the dominant perennial grass, redgrass (*Bothriochloa macra*), was ranked 1st in 80% of quadrats, with the weed species *Hypochoeris radicata* (flatweed), hairy panic, and stink grass ranked 1st in 2.2%, 1.5% and 0.7% of quadrats respectively.

The weeds that dominate the phalaris catchment are active in summer when phalaris is not competitive. During winter, both catchments contain the usual range of annual grass and broad-leaf weeds and clover. These account for less of the total feed on offer in the native grass catchment, because their early growth is suppressed by the native perennial grasses which continue to grow into autumn.

On side-slopes where phalaris and cocksfoot are persistent, they may be of greater benefit in reducing run-off and shallow through-flow, than they are in using more water. This is because in the 500 - 600 mm rainfall zone they are usually dormant in summer. Although their dense, robust, surface root systems may improve infiltration and reduce run-off, this must be balanced by an equivalent increase in water use, otherwise they will contribute to recharge.

Summer-active lucerne persists in mid-slope pastures in the Kyeamba Valley provided soils are 80cm or more deep. Around Wagga it will persist in cocksfoot pastures but it may be less persistent with phalaris. On its own, lucerne does not control run-off. Consequently, run-off and erosion rates under pure lucerne pastures are higher than grass based pastures (Edwards 1987). Although not as deep rooted as trees, lucerne can close its canopy and quickly achieve high rates of water use. Trees may take several years to achieve maximum water use (Clifton 1993). Strip cropping with lucerne at a ratio of 30% lucerne and 70% annual crop/pasture by area may achieve a balance between the low water use associated with cropping and annual pasture, and the high water use potential of lucerne without the use of trees. Of course, lucerne is only an option where soils are not acid.

Saline discharge areas require careful management because they contribute to the surface wash-off of salt from catchments. Although they can be stabilised with vegetation, and run-on and run-off can be controlled using diversion banks, they will not go away unless the recharge contributing to the problem is controlled. Saline sites can be re-vegetated using salt-tolerant shrubs (mainly salt bush - *Atriplex* spp. and blue bush - *Maeriana* spp.) planted on mounds, and these can provide useful forage from otherwise unproductive land. The range of commercially-available grasses for planting on discharge areas is limited to tall wheatgrass (*Thinopyrum ponticum*) and marsh grass (*Puccinellia ciliata*). Of these, tall wheatgrass is more readily available and more productive.

Management

The goal of managing pastures to maximise their water use depends on having pastures containing perennial species that are capable of using water where it needs to be used on the landscape, and allowing green leaf to accumulate, at least periodically, between the end of spring into autumn.

'Drought-proofing' strategies

Faced with drought and declining soil moisture reserves, all plants, including trees, try to reduce their water use. This is not a problem, because if moisture is in short supply, recharge is unlikely and the small amounts of water used will be all that is needed to keep the water balance in check. The main management risk faced during drought is that pastures become overgrazed to the point that perennial species are lost and there is a subsequent switch towards a higher proportion of annual species when the drought breaks.

In southern Australia, droughts are part of life. However, it is most important not to fall into the trap of opening all the gates and encouraging sheep and cattle to become pasture managers. Selective grazing by sheep in particular severely damages drought-stressed perennial grasses. For as long as pastures are grazed, they should be rotationally rested so that individual plants have time to recover between grazings.

Some pastures are irreplaceable - they are simply too difficult or too expensive to cultivate and sow, or too risky. Hill paddocks, where most of the recharge areas are, fall into this category. These pastures are part of a farm's asset base. They cost virtually nothing to keep, but once they are gone they have gone for good, and the impact of their passing can be far-reaching. These pastures need to be kept at all costs.

Some pastures can be easily and economically replaced. Others may be in some phase of a rotation and therefore may be earmarked for replacement anyway. The economic impact of grazing these pastures into the ground is relatively more favour-able than the consequence of losing everything. Restricting damage to the smallest area possible is another way of minimising losses, and if hand-feeding becomes necessary, weeds bought in with hay are easier to control if the hay is fed out on one or 2 paddocks only than over the whole property.

Sustainable grazing management

It is difficult to prescribe a strategy for grazing pastures, because at the farm level, many factors such as paddock size, pasture type, and landscape class interact. However, it is clear from several current experiments that set stocking at high rates is detrimental to most pasture types, especially those that contain a range of species of varying palatability and seasons of growth. Pastures and animals also perform much better if grazing is managed so that paddock stocking rates are matched continuously to the feed on offer, so that at the end of a period, grazing is complete and the majority of the forage is grazed off while its quality is high.

Extremely intensive rotational grazing systems such as cell grazing are reported to achieve high stocking rates and high levels of utilisation with virtually no detrimental change in pasture botanical composition such as weed ingress or loss of perennial species. Set stocking, which is the other extreme, may result in low productivity, detrimental changes in pasture composition and long-term decline in landscape health. Somewhere in-between will lie a grazing system that most landholders will be comfortable with, which will also meet the need to manage water use and lessen the risk of increasing dryland salinity. PROGRAZE is a good place to start to work out a sustainable grazing strategy for your farm.

Conclusions

Botanical change caused by agricultural land use and management is at the heart of the problem of accelerated recharge. Finding a balance between introduced exotic pasture, trees, native pastures and matching these to land-class units is the key to landscape health. Summer activity, perenniality and deep root systems are the keys to using water efficiently.

Rainfall timing and amount is the driving force for recharge and pasture management needs to insure against its unpredictability as much in times of drought as in the high-risk wet years. In general, the PROGRAZE approach to pursuing pasture quality and optimum animal production will also stabilise botanical change and promote better use of water. Wherever possible, maintain the tussocky nature of the pasture. Manage according to land class and don't plant pastures where they have dubious ecological advantage.

In terms of water use, the benefits of native pasture are often ignored despite their obvious adaptation to this continent and its climatic environment. In particular, consider the advantages of native C4 dominant pastures, with their ability to grow and use water over summer, when many other species are dormant.

Acknowledgments

I would like to gratefully acknowledge the extensive editorial assistance given in preparation of this paper by Bill Johnstone. I also wish to thank Bill, Peter Simpson and Denys Garden for their helpful consideration during a very difficult period.

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