NSW DPI

KEY SITES – LAND USE TO MANAGE WATER AND SALT

Land use recommendations from integrated hydrology research in the Lachlan Catchment - *the Bray's Flat Catchment Research Site.*

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The information contained in this publication is based on knowledge and understanding at the time of writing (January 2006). However, because of advances in knowledge, users are reminded of the need to ensure that information on which they rely is up to date and to check the currency of the information with the appropriate officer of New South Wales Department of Primary Industries or the user’s independent advisor.

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The Bray's Flat Catchment Research Site

INTRODUCTION

This document outlines dryland salinity research that has been undertaken at Bray's Flat Catchment in Central West NSW. The report outlines the increase in understanding that this research has brought about as well as the step by step increase in understanding how water and salt moves in this landscape. The Bray's Flat story has significant implications for the management of dryland salinity in NSW and the investment of public and private funds to change catchment scale outcomes.

Since the early 1990's there have been several studies into the catchment and its management, culminating over the last 5 years with a series of research projects that have explored how the catchment acts and reacts from micro scales to whole of catchment. These recent research projects are described briefly and some of their results are summarised. However, overwhelmingly, this document is an attempt to synthesise rather than just report, and provides the first 'draft' of the overall implications of the research for the management of the catchment as a whole, and for the investment of public and private funds for salinity management in particular, and better catchment outcomes in general.

As the research projects at Bray's Flat continue to add more information about the catchment, the initial conclusions and recommendations in this report may need to be modified – however, while more information may further clarify how Bray's Flat Catchment behaves and can be better managed, our understanding will never be perfect. On the basis of the information already gathered and analysed, Bray's Flat has many lessons for salinity management in NSW.

THE STUDY SITE

Bray's Flat is a first order catchment (~740ha) in the Lachlan River Catchment, near the southern border of the Macquarie catchment in central western NSW. It has an ephemeral stream (Bray's Flat Creek that joins Gumble Creek and then drains into Mandagery Creek) running from the south west to the north east and a saline scald (~10ha) at the outlet of the catchment. Bray's Flat is~20km north of Manildra.

The long term median rainfall at Bray's Flat is 600 mm, with a long term monthly median of 42 mm. Average annual temperature of 15^{o}C and potential evaporation peaks at 245mm in January and exceeds average rainfall in all except two months, giving Bray's Flat a semi-arid climate.

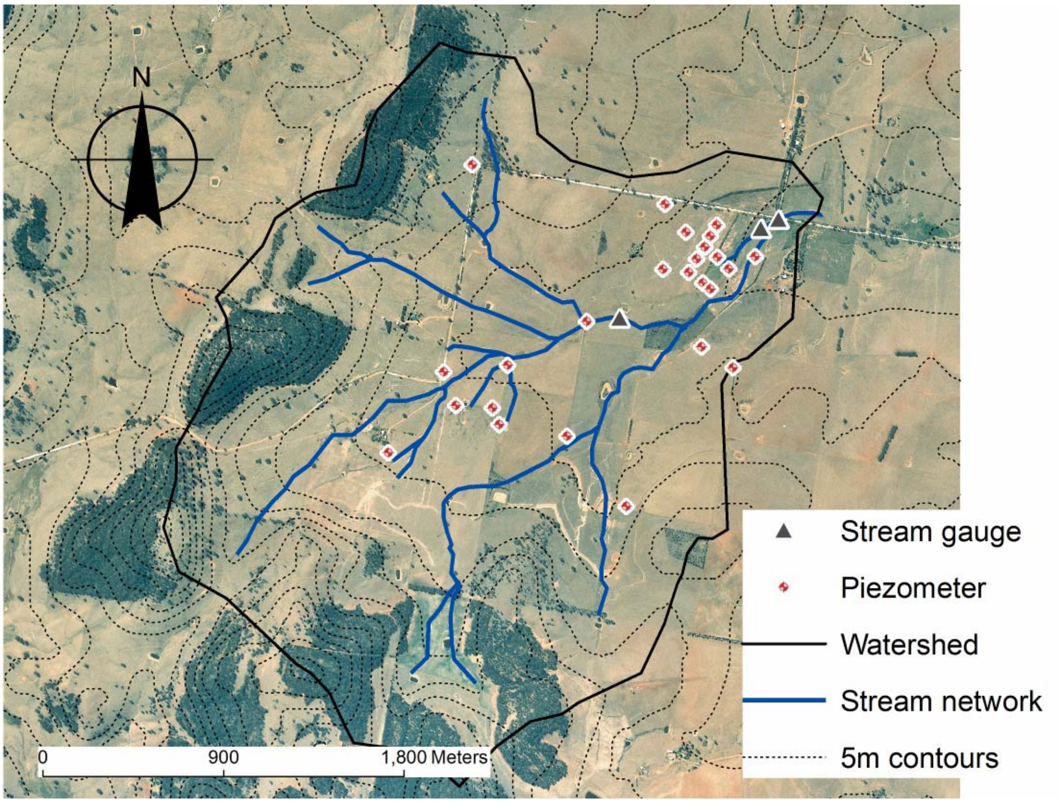

Figure 1 The Bray's Flat Catchment site

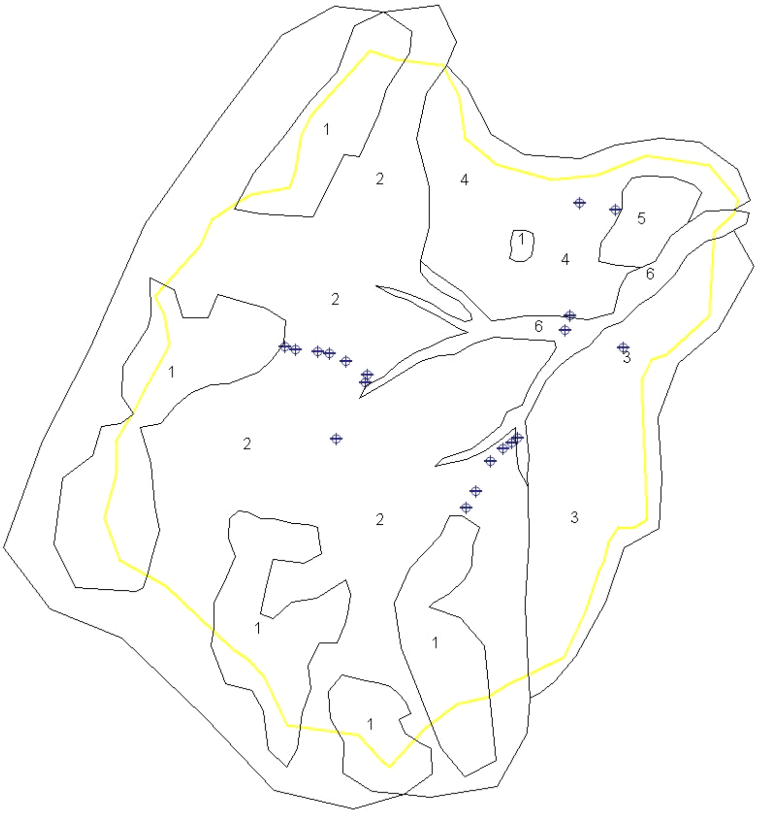

Figure 2 Soil map of the Bray's Flat site. A description of the main soil types is provided in Table 1.

Table 1 – Soils of the Bray's Flat catchment

Number (from Fig 2)	Soil Type	Description and comments
1	Lithosolic rudosol	Stony or gravely soil with exposed fractured bedrock and shallow poorly developed soils
2	Yellow sodosols	Texture contrast (duplex) with a sodic dispersive B horizon. Since the B horizon is poorly drained, saturation in the A horizon will develop in most winters or wetter periods.
3	Red chromosol	Texture contrast (duplex) B horizon not sodic or acid, soil, reasonably well drained soil, although tending to be sodic deeper in the profile
4	Red kandosol	Well drained/well structured gradational soil.
5	Salic hydrosol	Saline soil that is commonly waterlogged for 2 -3 months of the year.
6	Lutic rudosol	Relatively new soil based on alluvium showing little pedological development.

SOME HISTORY OF THE REGION

Bray's Flat catchment was cleared of remnant woodland to about the present proportions by 1900. Gully erosion was extensive in the early 20th century, but was ameliorated in the middle years of the century with graded banks and earth dams. Gullies have been back filled with earth, and current grazing and tillage practices are generally more conservative than the first half of the 20th century which reduces the likelihood of further erosion. This catchment is typical of most in the Eastern Murray Darling Basin where erosion control earthworks have been constructed since the 1940's in response to widespread soil erosion.

The current landholder has noted that the catchment was heavily eroded during his childhood during the 1950's. Cultivation associated with cropping was to blame for the increase in erosion. Buried fences and tree stumps were observed downstream of Bray's Flat catchment[1] in the 1990's.

The effects of dryland salinity in the broader district are observable on the first available aerial photos (1964) and has been noted by landholders since at least the 1920's. The salinity scald in Bray's Flat did not appear till after 1981, reaching its maximum extent in 1992 – it is therefore unarguably an example of secondary (human induced) salinity.

EARLY STAGE SALINITY PLANNING

In the early 1990's, a revegetation plan was put together for the Gumble Valley[2]. The Gumble Valley area is approximately 9000ha, of which the current study site forms a reasonably representative, 740ha sub-catchment at the upper end of Bray's Flat Creek.

The report said "*Classical salinisation/waterlogging due to over-clearing in the catchment is the dominant land management problem. It was first noticed in the 1920's and has continued to worsen. Salt is being brought to the surface by a rising water table. In 1990,*

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[1] Ellis, M.D., 1992. Factors affecting dryland salinity in the Gumble Creek catchment. BSc Honors Thesis, Maquarie University, Sydney, 134 pp.

[2] Anon (1993) A revegetation plan for the Gumble Valley

a year of above average rainfall, the watertable rose significantly and consequently waterlogged and salt affected areas increased significantly."

At that stage (1993), about 7% of the catchment was covered with 'bushland' and the plan proposed an additional 13% (1,150ha) be reafforested. There was only limited groundwater information, but it indicated positive pressure in the aquifer, rising groundwater, and that the aquifer was saline (not fit for human consumption). EC measurements indicated that water in Bray's Flat and Gumble Creeks was saline, that the trend was to increasing salinity and that salinity peaked in Gumble Creek.

The management recommendations for salinity and waterlogging included:

- Grow enough trees, in the right places for long enough to use enough water to lower the saline groundwater below the reach of the topsoil, crops and pastures.
- Identify and map all seepage areas on mid and lower slopes and plant blocks of trees above seepages.
- Experiment with a range of salt tolerant pastures and shrub spp (various saltbushes) in salt affected grazing lands.
- Trees can be planted in discharge areas to improve the appearance of the area, prevent soil erosion and assist in lowering the watertable.

The management strategies for pasture and cropland were:

- Increase the ratio of perennial to annual grasses on the mid and lower slopes.
- Use deep rooted crops and pastures such as lucerne, lupins and oilseeds.
- Minimise fallowing as a practice.
- Experiment with deep rooted native grasses as alternatives to introduced spp.
- Consider long term changes in farm practices that will minimise the use of chemicals and additives.

INITIAL CATCHMENT CLASSIFICATION

The Key Sites (see next section) project team developed a conceptual model at the start of the project from all available data, including digital elevation models, regional geology, borehole logs and electromagnetic induction (EM31) surveys. This data was then matched with the groundwater flow models contained in the National Classification of Catchments report[3] - see break out box for a summary. For Gumble, this indicated the most appropriate catchment classification was 'local model (iii) – discharge from weathered fractured rock aquifers at break of slope'.

In this type of catchment, it would be expected that the groundwater elevation would roughly follow the surface topography, and that the salinity expression at the lowest point in the catchment would be the result of clearing within the catchment as shown in Figure 3. The 'text book' response in this type of catchment is mirrored in the revegetation plan (developed in 1993 [1] and summarised above) and gives a good example of the early 1990's thinking about salinity and its management, including:

- The original vegetation was perennial and therefore agricultural landscapes needed to mimic the original water use;
- Planting trees (in this case ~600,000) was the most appropriate action overall;

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[3] Coram J et al. (2000) Australian groundwater flow systems contributing to dryland salinity – BRS report for the NLWRA dryland salinity theme

- Perennials (crops and pastures) always gave a better environmental outcome than annuals, and native pasture species would give a better outcome than introduced species;
- Recharge reduction was the best short and long term solution for salinity;
- Fallowing was viewed extremely negatively as a major promoter of recharge;
- ‘Upslope’ was the same direction for both the land surface and the groundwater;
- The trade-off’s between extent of salinity, catchment water yield, and stream water quality were not overtly considered – the focus was ‘overcoming salinity’.

The National Catchment Classification System

As part of the National Land & Water Resources Audit, a classification system was developed to provide a nationally consistent mechanism for describing catchment behaviour and potential management options. There are 15 individual ‘classes’, but they are aggregated into 3 flow systems:

1. **Local**. In these flow systems the groundwater circulates at a shallow depth, is usually unconfined. They operate over a scale of 1-3km with the recharge and discharge areas quite close together. Local flow systems tend to occur in sub-catchments with higher relief such as along the edges of plateaus and ranges. The systems are predicted to respond relatively quickly usually within 5-10 years after intervention.
2. **Intermediate**. The intermediate flow systems operate at a scale between local and regional – over a scale of perhaps 5-10km. They tend to occur in foothills and valleys and may be overlain by local flow systems. The systems are predicted to respond slowly than local systems usually within 40-100 years after intervention.
3. **Regional**. These flow systems have deep circulation depths, with the recharge and discharge areas separate by considerable distance – typically 50km or more. They are usually confined, have long groundwater residence times and are likely to be overlain by local and intermediate systems. Regional systems tend to be associated with broad riverine plains on depositional basins. The systems are predicted to respond the slowest and the prediction is that some systems will only respond within 150-200 years after intervention.

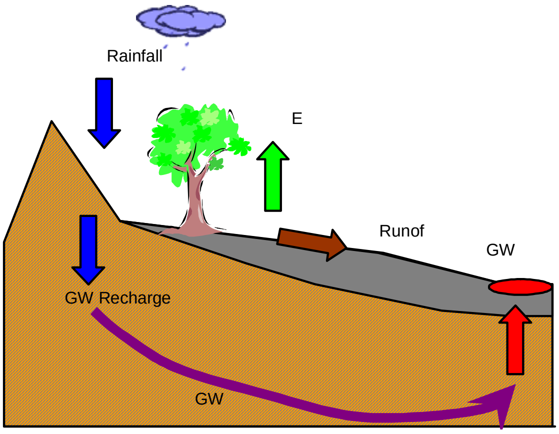

Figure 3 The initial conceptual model of the Bray’s Flat site, based on existing data and site observations. The model shows recharge predominantly from the upper slopes forcing groundwater to the surface at the saline scald (shown in red).

CURRENT CMA PRIORITIES AND FUNDING

Brays Flat is within the Lachlan slopes sub region of the Lachlan CMA, and landholders within this area are eligible for to apply for perennial pasture management, farm planning and training incentives. The perennial pasture management program's aim is improve soil organic carbon and groundcover and reduce salinity. In 2007 the LCMA will fund fencing and water supply to establish improved grazing management systems such as rotational grazing or time controlled grazing with incentives up to 30% or $65/ha based on the project size.

There are additional incentives offered by the LCMA however they are not targeted to the Lachlan slopes sub region.

THE BRAY'S FLAT SITE RESEARCH PROGRAM

One of the unique features of the Bray's Flat project has been the combination of projects and scales involved. Four individual 'projects' have provided the information on which this paper is based – 2 at the catchment scale, and 2 investigating specific sites/issues within the Bray's Flat catchment.

KEY SITES PROJECT

The Key Sites Project commenced under the NSW Salinity Strategy in 2003 and has been supported by the National Action Plan for Salinity and Water Quality since 2005. Bray's Flat is one of 8 research sites strategically located along the tablelands and slopes of NSW which are instrumented to answer the following questions:

- How do we account for water at a paddock scale and how does this relate to the catchment water balance?
- Where does the salt and water come from and where is it going?
- Are water and salinity models predicting results that are consistent with catchment observations?

CRC PROJECT

"Profitable sustainable farming systems by integrating woody and herbaceous perennials with annual-based cropping systems" (Trees and Water Use)

The CRC Project is also operating at the whole-of-sub-catchment scale, building on the data and knowledge from the Key Sites project, to:

- Quantify the competitive and complimentary productivity effects of integrating woody perennials with new and traditional pasture and cropping systems using systems in the central west region of New South Wales as case studies;
- Quantify hydrological impacts of different configurations of woody perennials integrated with herbaceous perennial pastures and traditional cropping systems in central west region of NSW, at paddock and at landscape scales;
- To provide economists, farm groups and land managers information needed to undertake economic and environmental assessments of the best profitable and sustainable farming enterprises involving woody and herbaceous perennials.

Widespread reafforestation is both unlikely (for economic reasons) and rarely desirable because of the impact on surface water supplies and quality. However, at a more local scale, tree belts have sometimes been shown to reduce recharge and/or to intercept the lateral flow of groundwater. This study investigated:

- the ability of trees to use water in recharge and discharge sites within Bray's Flat catchment;
- the ability of pastures to use water in recharge and discharge sites within Bray's Flat catchment; and
- the relative effectiveness in recharge and discharge sites of trees and pastures to mitigate the impacts of dryland salinity.

SUSTAINABLE GRAZING ON SALINE LAND (SGSL)

SGSL was part of the Land Water & Wool joint venture, with a focus on determining the financial, social and environmental implications associated with improved grazing systems for saline land. The NSW part of the project had sites at Bray's Flat and Young, with a focus on the effects establishing salt-tolerant pastures on saline discharge sites, on the export of salt and water as well as on animal production. Specifically to work on the saline discharge site at the outlet of the catchment and:

- Determine salt and water movement from salinised land under both volunteer/naturalised pasture and salt tolerant perennial pasture.
- Develop pasture management systems that maximise pasture and animal production, minimise negative on and off site environmental impacts and allow sustainable use of salt-affected land.
- Determine the economic value of the forage produced from these systems for wool and sheep production.

RUNOFF GENERATION AND MOBILISATION OF SOLUTES TO STREAMS

(PhD Project)

The processes and rate of mobilisation of salt to streams in the Eastern Murray-Darling Basin is poorly understood. Theory indicates that areas with saline water table close to the surface are likely to mobilise high volumes of salt to streams via direct groundwater flow and by rainwater and runoff collecting salt from above the water table.

By measuring the movement of water to the stream, and the chemical composition of that water (rain, groundwater and water that has mixed with the surface soil layers have different chemical signatures) it is possible to determine both the amount of salt being added to the stream, and the source of that salt.

Importantly, the reporting from individual projects back to the investors in that project has not been restricted to the projects' own results – knowledge gathered across all parts of the overall study has been incorporated and has influenced the conclusions and recommendations back to individual investors.

DISCUSSION OF KEY RESULTS

AT CATCHMENT SCALE

Upper Slopes

The ridge lines are highly porous and are certainly recharge zones. Using 100 years of rainfall records to model the catchment outcomes gives a prediction that under the native vegetation, an average of 52mm/yr of recharge would have occurred across the rocky ridges. The CLASS model also predicts that if the native vegetation were cleared and replaced with annual pasture, recharge would rise to 132mm/yr. However, the rocky ridges were identified as not suitable for agriculture during the early period of land clearing and have remained treed.

We can conclude that contrary to the general perception, the areas of remnant, native vegetation are significant recharge zones in the Bray's Flat Catchment. However, the recharge that is currently occurring, was already occurring pre-agriculture when salinity was not evident in the catchment. Therefore, while there is significant groundwater recharge from the upper reaches of the catchment, it is not these areas that are responsible for the emergence of salinity in Bray's Flat in the early 1980's.

Mid and Lower Slopes

The majority of the mid and lower slopes in the catchment are yellow sodosols, with a bleached A2 horizon (indicating perched water-tables) and a sodic subsoil that has a sufficiently low hydraulic conductivity (see Figure 4) to cause extended perching of the water table in the A2 horizon. This soil configuration suggests that extensive deep drainage is unlikely to occur on these soils, even with saturated conditions.

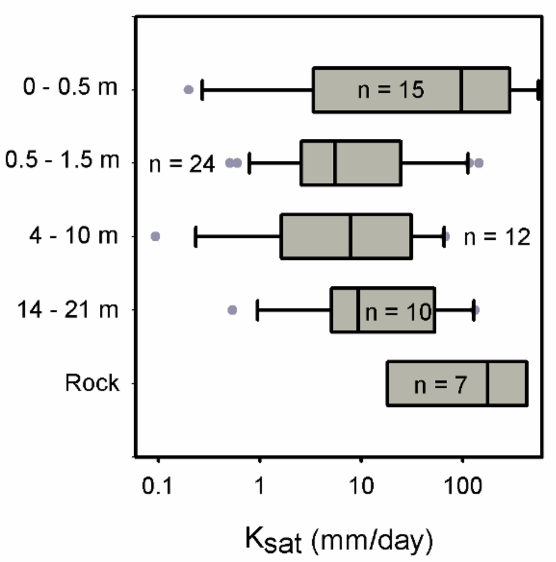

Figure 4 Variation of the saturated hydraulic conductivity down the soil profile. Data collected catchment wide and indicate that while the topsoil has reasonable conductivity (Ksat = 100mm/day), this drops to <10mm/day over the 0.5-20m depth.

To further investigate the pattern of water movement in the yellow sodosols, the chloride profile was investigated – see Figure 5. Chloride profiles give an indication of how much water has moved through the soil layers, because chloride is highly mobile and moves easily with the water.

Figure 4 gives an example of one of the chloride profiles, and shows a salt bulge between 4 and 10m. This is usually interpreted as the root zone limit of the original, deep rooted native vegetation that was cleared over 100 years ago and replaced with shallow rooted pasture. The soil moisture profile is driest between 5 and 10 m indicating that the original root zone has not been fully re-wetted during the time the pasture has existed (because the pasture could never extract water from this deep).

Only the top few metres of this profile are approaching field capacity suggesting that there has been little or no deep drainage below 5 m since the land was cleared, because while the saturated hydraulic conductivity is very low, conductivity of unsaturated soil quickly approaches zero. Indeed, 3 different methods to calculate the long-term deep drainage beneath the sodosols all gave estimates of less than 1mm per year.

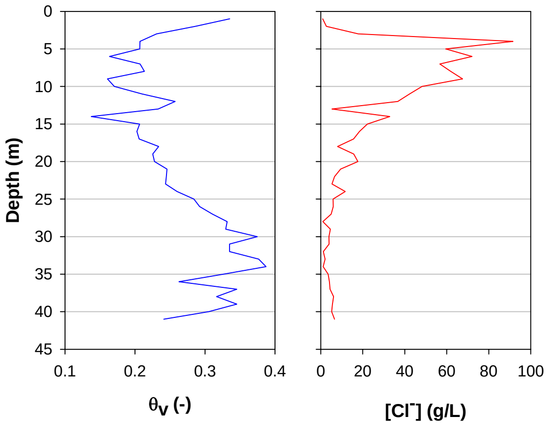

Figure 5 The soil water and chloride profiles at piezometer 234 showing the highest chloride concentrations and the lowest water contents over the 5-10 m depth.

Further evidence of the low levels of deep drainage from the yellow sodosols soils has been provided by the tree and pasture water use study discussed in the Sub-Catchment Studies section below.

We can conclude that contrary to the general perception, clearing the slopes in the Bray's Flat Catchment is unlikely to have increased recharge significantly above what would have been occurring under the native vegetation – ie before clearing – so that clearing the southern slopes was not responsible for the emergence of salinity in the catchment. In addition, changes in agricultural land management (for example, annuals, perennials or even fallow) on the slopes will not affect recharge but may affect run-off.

Groundwater Flow

The generalised groundwater model for this catchment that was developed at the start of the overall project (see Figure 3) indicated that the direction of groundwater flow would roughly follow the direction of the surface contours as the groundwater recharge would be from the ridges and slopes, forcing the groundwater to the surface at the lowest point in the catchment.

Extensive groundwater measurement and modelling have now clearly demonstrated that instead of following the general direction of the surface water flows, the groundwater is flowing in almost the opposite direction – see Figure 6. Recharge from the upper slopes is not linked to the discharge at the low point in the catchment, but could be contributing to groundwater discharge in adjacent catchments.

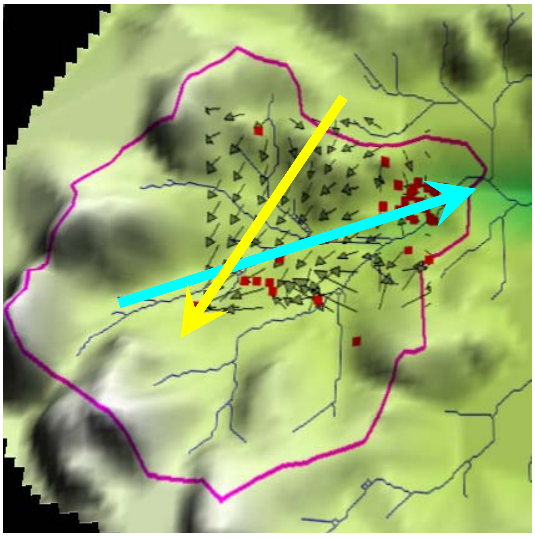

Figure 6 The blue arrow indicates the direction of surface flow in the Bray’s Flat catchment, while the yellow arrow indicates the broad direction of the groundwater flow.

We can conclude that contrary to the general perception, and contrary to the catchment model in Figure 3, the groundwater in Bray’s Flat Catchment is flowing in almost the opposite direction to the surface water. This strongly implies that the groundwater causing the salinity in Bray’s Flat catchment is sourced from outside the catchment and that neither the original clearing of Bray’s Flat Catchment, nor the land use since has contributed to the expression of salinity. However, given that Bray’s Flat Catchment has a significant area of secondary salinity, part of the cause is most likely to be clearing and land use changes outside the catchment boundary.

Catchment Runoff

In order to determine the sources of runoff in the Bray’s Flat catchment, a sub-catchment was selected (367ha as shown in Figure 7) as representative of the catchment as a whole, less the saline area (10ha). The full catchment could not be used for this study because the flume at the catchment outlet has mixed runoff from the saline and non-saline areas.

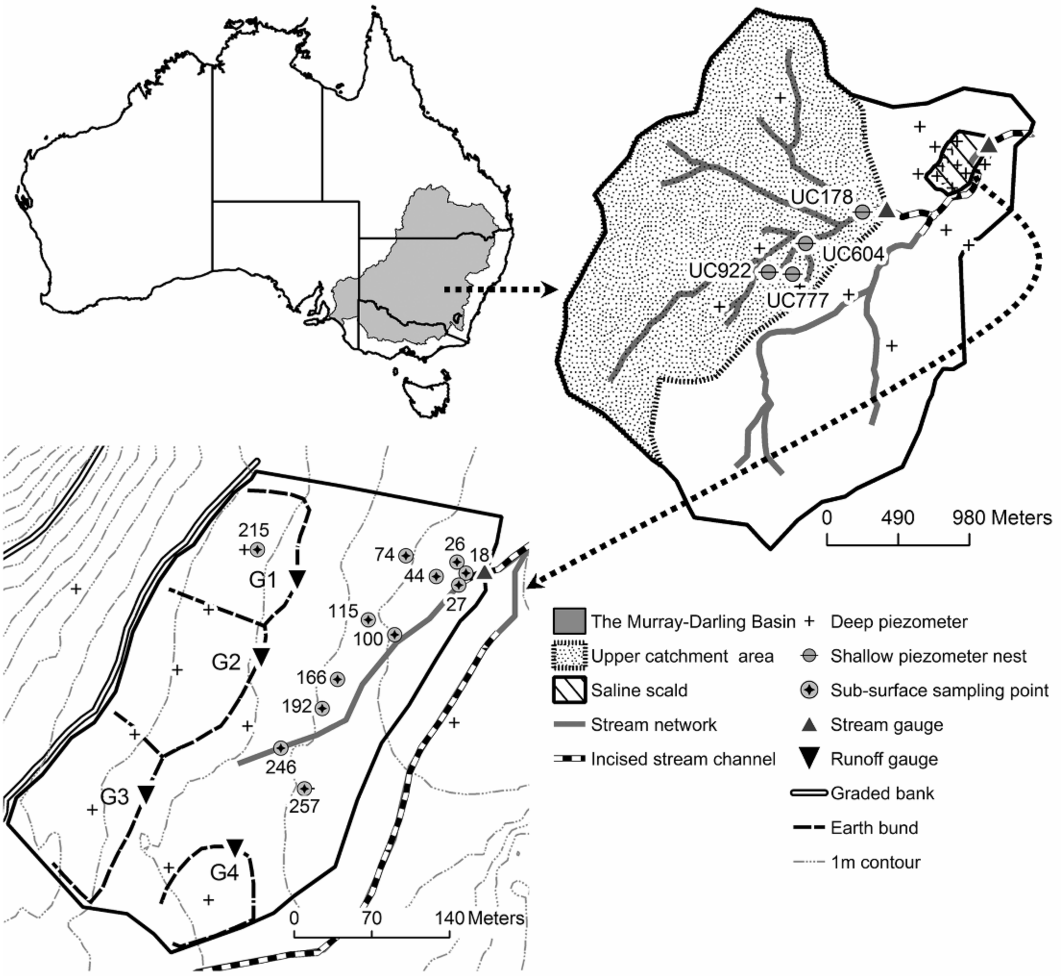

Figure 7 The large shaded area represents the section of the catchment selected to represent the non-saline areas for runoff measurement, while the small hatched area is the saline scald.

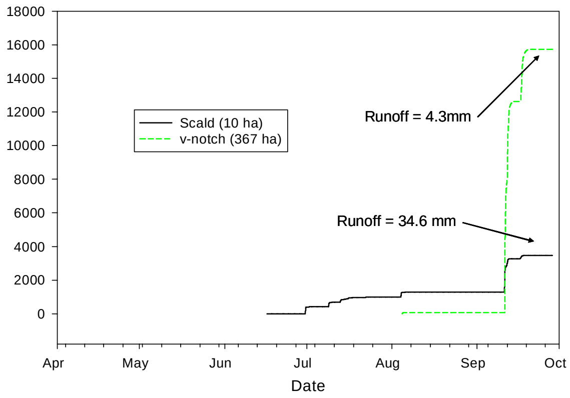

Figure 8 Cumulative runoff (m3) from the shaded and hatched areas outlined in Figure 6.

Runoff from the saline scald began in July, about a month before the first minor flows from the rest of the catchment. A major event in September boosted the runoff from the non saline areas so that over the entire period there was 4.2mm of runoff per hectare from the non-saline areas and 34.6mm/ha from the saline scald. The net result was that 1.3% of the catchment (the saline scald) provided 11% of the total run-off from the catchment.

Table 1 Runoff and salt export April-October period 2005 from the upper catchment and scalded areas in Figure 7

	Upper catchment area	Scalded area
Total runoff (m^3)	15720	3460
Total runoff (mm)	4.2	34.6
Salt export (t)	0.58	5.38
Area weighted salt export (t/km^2)	0.15	53.8
Flow weighted EC (µS/cm)	54	2314

We can conclude from the runoff studies that most of Bray's Flat Catchment is producing a significant amount of high quality run-off – a valuable input into the Lachlan Catchment. On the other hand, the small saline area at the outlet of the catchment is making a contribution to the total runoff from the catchment considerably greater than its area would suggest. In addition, virtually all the salt being exported from the catchment (as stream flow) is coming from the saline scald, and this salt is mixing with the fresh water run-off from the upper catchment. We can further conclude that while management actions to reduce recharge in Bray's Flat Catchment would have no local benefit, improved management of the discharge site could yield significant improvements in the quality of water leaving the catchment.

Buried Soil

The current landholder reported that as a child in the 1950's, he remembers a fence along the creek-line being almost completely covered by sediment and that later it completely disappeared. This suggests that the land surface of the current saline site has generally been 'raised' as sediment from the upper catchment has settled onto the site.

Indeed, soil cores from the saline/discharge site have confirmed the value of historical anecdotes and revealed a buried soil profile about 1m below the current soil surface – see Figure 9 – and a gravel layer at ~1.5m that is most likely the original stream bed of an incised stream.

Figure 9 A buried soil profile, similar to the saline site in the Bray's Flat catchment – the old soil surface is half way down the photo, highlighted by the green line.

The likely impact of this filling-in of the incised stream and raising the valley floor has been investigated through modelling the current situation (the ground surface at its current level) and comparing that to a situation with the previous land surface and an incised channel. The results from this modelling can be seen in Figure 10, and indicate that the water table below the saline scald in the Bray's Flat catchment is higher than it would have been if the erosion and deposition had not occurred. There are positive and negative aspects. On the positive side, more salt is being stored at the site, with less base flow of salty water into the stream. On the negative side, the impact on the farm from the higher watertable and increased salt storage is negative for production and amenity.

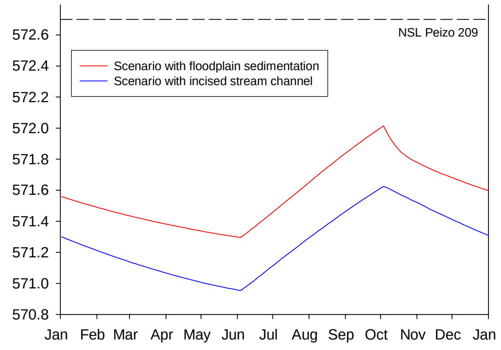

Figure 10 Predicted groundwater level under the two scenarios – current situation in red and the prior situation in blue.

We can conclude from the physical evidence and the modelling studies that the in-filling of the original stream in the middle period of the 20th century is at least partly responsible for a more severe salinity situation in the 1990's and beyond, by raising the water table by approximately 0.4m and increasing the amount of salt stored at the site. We can also conclude that there is a considerable conflict of interest between the farmer's interests and the catchment community's interests. The local situation would be considerably ameliorated by digging the stream bed back down to its original level and increasing the groundwater flow into the creek – an illegal action under current legislation. The catchment situation would be improved by taking the opposite action and increasing the salt storage at the site, therefore reducing the salt input into the creek.

Overall Conclusions at Catchment Scale

Overall, we can conclude that the physical evidence collected from the Bray's Flat Catchment has significantly undermined the original classification that was presented earlier in this report and is summarised in Figure 3. Bray's Flat Catchment has proven to exhibit few of the characteristics outlined in Figure 3 and is clearly **not** a local flow system. Based on the new evidence, the catchment can now be conceptualised as shown in Figure 11. The identified recharge zone is outside the surface water catchment and therefore it is an intermediate (rather than local) groundwater flow system. The correct classification from the National Groundwater Flow Classification system is GFS model 4.11 - an intermediate groundwater flow system (iii) - discharge from unweathered fractured rock aquifers at break of slope.

The source of the groundwater that is discharging at the saline site in Bray's Flat Catchment has not been identified. To do so could require significant additional resources, depending on the distances involved.

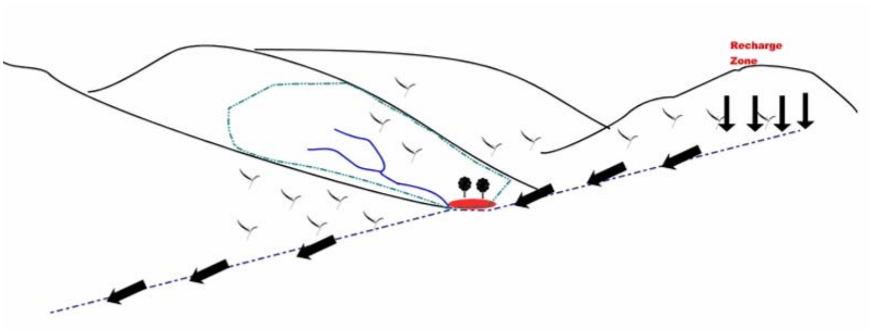

Figure 11 Current conceptual model of the Bray's Flat catchment. The blue line indicates Bray's Flat Creek, the dotted blue line shows the groundwater, and the filled arrows show the direction of flow.

AT SUB-CATCHMENT SCALE

There were 3 aspects to the research at the sub-catchment scale that have provided additional insights into the behaviour of the catchment, and the options for future management:

1. How saltland functions hydro-chemically and hydraulically;
2. The effect of saltland pasture production on the saline, discharge sites on salt and water movement from the discharge sites; and,
3. The potential of trees to increase water use from the discharge site, and from further up-slope.

Results from these 3 aspects are presented below - Figure 12a shows the locations of the plots, while Figure 12b provides an EM map of the saline site

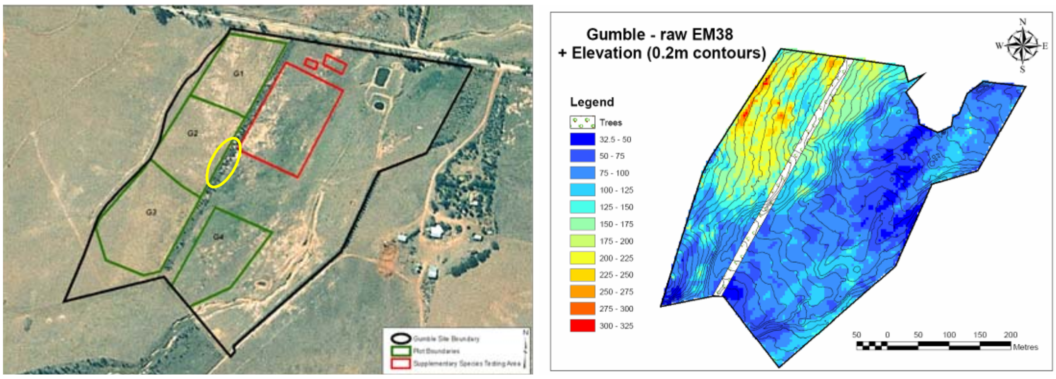

Figure 12a and 13b The saline scald at the catchment outlet, showing the main 4 SGSL plots in green and where a range of additional/alternative saltland pasture species were trialled in red. In addition, the area of the tree belt used for the tree water use study is outlined in yellow. The EM 38 map shows the variation in salinity across the site, highlighting that plots G1 and G2 are the most saline.

Saltland hydrology

Earlier in this report, it was outlined how the saline site was making a much greater contribution to salt and water runoff from the catchment than its area would indicate (see Figure 8 and Table 1). Further studies were undertaken to clarify the make-up of the water running off from the saline, discharge area. By chemically analysing the run-off water, it is possible to determine the contribution directly from rainfall, from water from the'near surface' soil zone, and from the welling up of the groundwater itself. The pattern for a typical rainfall event is shown in Figure 15. In this case, the relative contributions to runoff were: rain 73%, near surface zone 11% and groundwater 16%. The relative contributions to the salt load were very different – rain 0%, near surface 77% and groundwater 23%

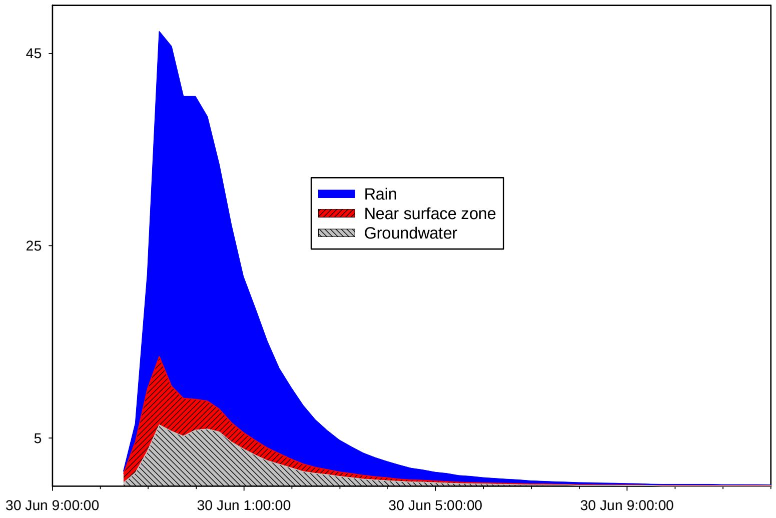

Figure 14 A runoff event in late June 2005 showing the changing contributions from rain, the near surface zone, and the groundwater over the time of the runoff event.

From the saltland hydrology research, we can conclude:

- *Most of the salt and all of the saline stream flow leaving the catchment is generated from the scald area.*
- *Within the scald most of the salt comes from the near surface zone (ie salt washoff), rather than directly from the groundwater.*

Effect of pastures on salt land

After pre-treatment hydraulic calibration, 2 of the 4 SGSL plots shown in Figure 12a (ie G1 and G3) were sown to an improved pasture, using a shotgun mix of grasses (tall wheatgrass, puccinellia, fescue, and phalaris) and legumes (strawberry, balansa and persian clovers, plus burr medic). The advantage of a shotgun mixture was highlighted by the small plot studies of alternative saltland species that indicated none of the saltland species was particularly well suited across the site, and that the local couch grass was well adapted but not particularly productive.

The pastures were sown in autumn 2005 and established very successfully. Evapotranspiration from the sown pasture plots has been significantly increased (see Figure 13) which shows the relationship between plots G1 and G2 (the most salt affected plots). Prior to sowing, evapotranspiration from both plots was very similar, giving a line that approximates a 1:1 ratio or 45 degrees. After sowing, evapotranspiration from the sown plot (G1) increases quite dramatically, so that the line is more like 2:1 than 1:1. This increase in evapotranspiration has been confirmed by soil moisture measurements, showing a greater deficit under the sown pasture.

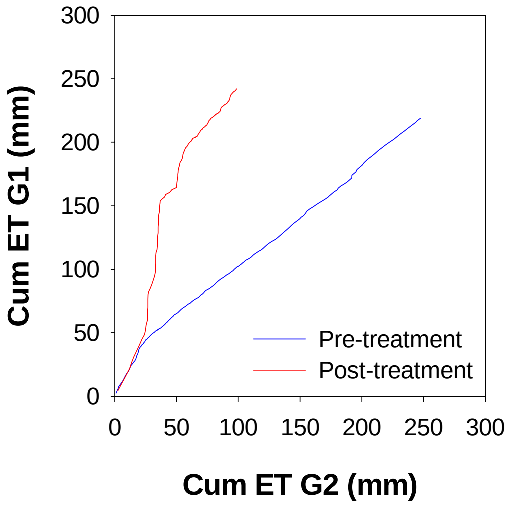

Figure 15 Comparative ET from sown and unsown plots showing a dramatic increase in the relative ET after sowing a saltland pasture.

The effect on evapotranspiration occurred despite the fact that the control plots responded very positively to the grazing management that was imposed. Prior to the project, the saline site was part of a larger paddock, resulting in preferential grazing and significant areas of bare ground. At the start of the project (June 2003), both the plots shown in Figure 13 had 44% bare ground. By June 2006 (12 months after pasture establishment on plot 1) the amount of bare ground had reduced dramatically – to 13% on the sown plot and to 15% on the 'control' plot.

The impact of sowing a pasture on the run-off from the plots is less clear cut, though increased evapotranspiration, increased soil water deficits and increased infiltration all indicate that run-off from the saltland pasture plots should be significantly less than from the controls. A major problem is that there have been so few run-off events since the saltland pasture was established, and the project has been extended to try and overcome this limitation.

What has been clearly shown is that there was a significant increase in the amount of salt in the runoff water from the recently sown plots – probably as a consequence of the disturbance that occurred during the pasture establishment process, allowing more mixing with the runoff water. This was despite the soil disturbance being minimised by direct drilling (rather than cultivating and sowing) the pasture. It is expected that this increase will prove to be a transitory effect and that a new equilibrium will be reached.

From the saltland pasture research, we can conclude:

- *Simply fencing off saline sites and grazing them conservatively (as in the control plots) can lead to significant rehabilitation by dramatically reducing the area of bare ground.*
- *Saltland pastures can have a significant impact on local-scale hydrology, with increased evapotranspiration, soil water deficits and infiltration, plus decreased runoff.*
- *In the short term at least, the soil disturbance associated with pasture establishment is likely to increase salt export.*

Impact of Trees

Planting trees has been seen as part (or sometimes all) of the solution to dryland salinity, but the most effective location and spatial arrangement of trees remains problematic. The potential role of trees in the Bray's Flat catchment was investigated by looking at the water use of existing tree belts in recharge and discharge areas and comparing the tree and pasture water use. [*Note, the tree studies in the upper catchment were designed before the* *project team concluded that land management on the slopes of Bray's Flat Catchment was irrelevant to catchment salinity*.]

In this study, tree water use (or transpiration) was estimated from sap flow sensors installed into the trunks of 6 trees in both the discharge and recharge tree belts – casuarinas in the discharge site and a mixture of casuarinas and eucalypts in the recharge zone. Pasture water use (evapotranspiration) was more directly estimated using Bowen Ratio equipment which incorporates both plant and soil evaporation. As a result, comparisons between trees and pastures are less direct than the comparison between recharge and discharge sites within either trees or pastures.

Daily transpiration estimates for the discharge and recharge tree belts are presented in Figure 15. The differences are quite dramatic, with the recharge tree belt transpiring 536mm over the 18 month period shown, while the discharge tree belt transpired 1391mm. For the pasture sites, the corresponding values (but for evapotranspiration) were 1006 (recharge) and 1158 (discharge) – ie, nowhere near as dramatic a difference.

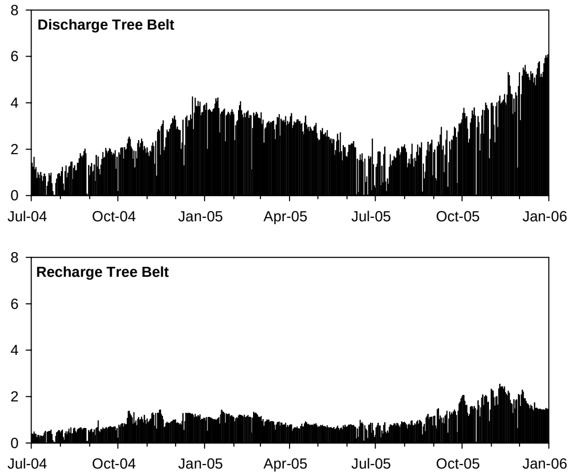

Figure 16 Transpiration estimates from tree belts in the discharge and recharge zones of Bray's Flat Catchment.

Groundwater levels beneath the tree and pasture areas were also monitored. Data for the recharge areas are not presented as the water table was ~11m below the ground surface and therefore not accessible to either the trees or the pasture. In effect, both trees and pasture were limited in their water use to the rain that fell, less any runoff, with deep drainage a negligible term in the water balance. In addition, the differences in transpiration between the tree blocks shown in Figure 15 was increased by the greater sapwood area (water conducting 'pipes') present in the discharge tree block.

At the discharge sites, the water table was consistently within one metre of the soil surface, allowing the discharge pasture to utilise 150mm more water than the recharge pasture (over the 18 months shown in Figure 15), while the discharge tree belt used a whopping 1144mm more than the recharge tree belt. However, direct evidence that this large difference in water actually lowered the water table appreciably under the tree belt compared to under the discharge pasture (Figure 16a and 16b) is not available. Figure 16 shows the water table depth under the pasture and near the tree belt – the tree belt was too dense to allow drilling equipment without damaging the trees, an impact not acceptable to the land owners. Indirect evidence (drier soil profile measured with a neutron moisture meter) does suggest water table drawdown.

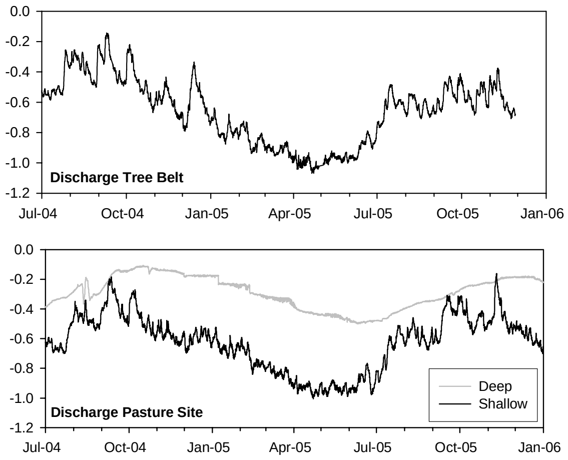

Figure 17a and 18b Water table depth near the discharge tree belt and beneath the discharge pasture site.

Long term modelling showed that the additional water use by the trees on the discharge site was sufficient to reduce run-off from the tree site to almost zero, with significant implications for the movement of salt into the stream.

We can conclude from the tree and pasture water use studies that:

- *The tree and pasture water use data from the recharge area supports the earlier conclusion that deep drainage (ie recharge) is not a significant component of the water balance on the yellow sodosols that make up the mid and lower slopes of the Bray's Flat Catchment.*
- *The pasture on the discharge site was able to use slightly more water than the pasture on the recharge site, but the differences were relatively minor compared to the differences between the tree blocks*
- *The trees on the discharge site used much more water than the trees on the recharge site or either of the pasture sites, by accessing the groundwater.*
- *The most effective place to plant trees in the Bray's Flat catchment (for water and salinity management) is in the discharge site. Tree plantations in the hypothesized recharge zone may well be a viable proposition. This has not been investigated and therefore cannot be discounted*

MAJOR CONCLUSIONS AND RECOMMENDATIONS

As the results from the various studies at Bray's Flat have been presented above, individual conclusions have been drawn. Those conclusions have been aggregated into the 6 major conclusions presented below, and for each conclusion, management recommendations have been provided.

Conclusion 1 – Bray's Flat is not a local groundwater flow system as initially categorised, but an intermediate flow system with the saline groundwater being sourced from outside the surface water catchment boundary.

Recommendations

1. The management recommendations associated with the 1990's salinity plan for the Gumble Catchment (essentially revegetation and perennialisation of the mid and upper slopes to reduce recharge) should be largely ignored.

2. There should be no public investment in revegetation to prevent recharge in the Bray’s Flat Catchment as it would not result in any improvements at the saline site or in downstream salinity.

Conclusion 2 – the upper slopes/ridges in Bray’s Flat Catchment are significant recharge zones despite retaining much of the original native, deep rooted vegetation. Clearing these areas would increase recharge further, but this would be unlikely to have any impact within the catchment.

Recommendations

1. The native vegetation remaining on the upper slopes of Bray’s Flat Catchment should remain uncleared.
2. Public investment to help protect (and potentially improve from a biodiversity perspective) the remnant native vegetation is probably appropriate. This might include support for fencing and/or the creation of corridors to link the existing remnants.

Conclusion 3 – clearing the mid-slopes in the Bray’s Flat Catchment has not increased recharge and did not contribute to the emergence of salinity in the catchment. Catchment salinity outcomes are more or less independent of any management actions on the slopes.

Recommendations

1. The mid slopes should be managed by the landholder with a focus entirely on profit and sustainable land management.
2. Annuals, perennials and even fallow may be appropriate on midslope areas. if supported by economic outcomes.
3. The only public investment that could be justified for the mid slopes would relate to the protection of the soils in order to ensure good quality surface water flows from the slopes and into the stream.

Conclusion 4 – the deposition of sediments from the catchment onto the (now) saline site in Bray’s Flat has raised the water table and increased the local salinity impact, creating a clear ‘conflict’ between the best outcome for the landholder (restoring the original stream bed depth to reduce the salinity expression) and the catchment (maintaining, or even increasing the salt storage on-site).

Recommendation

1. There is a clear case for public investment to improve the ‘management’ of the saline area in Bray’s Flat Catchment so as to increase the storage of salt on the site (decrease the flow of salt into the stream) and to compensate the landholder for the additional salt storage and its local impact.

Conclusion 5 – the small (~10ha) saline area at the outlet of the catchment is making a contribution to the total runoff from the catchment considerably greater than its area would suggest. In addition, virtually all the salt being exported from the catchment is coming from the saline scald, and this salt is polluting the fresh water run-off from the rest of the catchment. Currently the data suggest that establishing a salt tolerant pasture on the scald has increased the salt export of the site. Additionally there is no data to support the concept that increased groundcover decreases salt load. However this is a key question that should be investigated by on going monitoring of the Brays Flat scald.

Recommendations

1. The clear priority for public investment to improve the salinity ‘outcome’ from the Bray’s Flat Catchment is management of the discharge site. As the majority of the salt entering the stream is sourced from the ‘near surface’ zone (salt washoff), increasing

groundcover and water use should may give significant improvements. Initial indications are that fencing should be the first priority, with saltland pastures and (especially) trees providing additional water use and potential salinity benefits.

2. Ongoing investigation to the effect of fencing off the scald and improving groundcover on the salt load leaving the scald.
3. Improved amenity is a key outcome to assist with compensating landholders for potentially greater salinity stores on their farms.

Final Conclusions, Comments and Recommendations

Conclusion 6 - Bray’s Flat Catchment has highlighted that management interventions to reduce recharge are ‘riskier’ than interventions to better manage discharge.

Comments

1. Identifying recharge sites is inherently difficult (of 8 study catchments in NSW, detailed investigation has overturned the initial catchment classifications made by local experts in 5 cases), while identification of discharge sites is relatively simple, due to the visual nature of these sites.
2. Discharge sites are typically small (~2% of the catchment in Bray’s Flat) while recharge areas are large and diffuse, potentially allowing much greater investment per ha on the discharge sites to achieve an improved catchment outcome.
3. The chance of getting a negative outcome from recharge management (especially a reduction in fresh, surface water flows) is high, while the chance of getting a negative outcome from improved management of discharge sites is low. [Note – recharge management in Bray’s Flat Catchment would have had no impact on recharge and only minor impacts on surface flows, but would have been at considerable cost and so is included as a ‘negative outcome’.]
4. Management interventions that prove to be ‘incorrect’ can be identified relatively quickly on discharge sites as the impacts have to be local. However, for recharge management, many years (decades?) may pass before an ineffective intervention can be identified as such.

Recommendation

1. Management interventions (including those assisted by public funding) on and near any discharge sites should be the first salinity management response in all catchments unless the source of the recharge is both rigorously identified (expensive) and relatively close to the discharge site (ie a local flow system).

Conclusion 7 The individual research projects have added significant information to the public domain, but the defendable conclusions and recommendations are only possible because of the collective understanding at large and small scales within the catchment.

Comments

1. Many of the conclusions and recommendations about and for Bray’s Flat Catchment are only possible because of the range of information collected over a range of temporal and spatial scales. Such intense information collection will be possible in only a minor number of catchments and a process must be found to generalise from such work to assist the management of the vast number of catchments for which no detailed information will ever be collected.

Recommendation

1. The intensive baseline data collected on the site enables Bray's Flat to be part of a suite of long term land and resource condition monitoring sites. Funding arrangements should be pursued to facilitate this outcome.

Additional Information Requirements

A major research effort has been directed into the Bray's Flat Catchment, with significant changes to the management recommendations for both public and private investment that may relate to salinity management. However, as always, significant gaps in knowledge remain. The most significant seem to be:

1. Quantifying the catchment outcomes (potential reductions in downstream salinity) from the range of interventions that are possible at the discharge site. These interventions range from fencing and natural revegetation, to specific saltland pasture, to shrubs and trees. Bray's Flat research suggests that catchment benefits will increase across that range of interventions, but this must be quantified in order to assess the likely return on (especially) any public investment in discharge site management.
2. Management of recharge sites should be pursued as part of sustainable land management practices promoted by NSW DPI. These activities include establishment and management of perennial pastures and conservation cropping.
3. The series of studies presented in this report highlight the increased understanding that can arise when agencies take a long term integrated approach to natural resource management research. Agencies should not look solely at providing outcomes to the investor but using the investment to pursue long term integrated and strategic research goals.

FURTHER READING AND REFERENCES

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