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Setting targets for resource condition in Upper Crossman catchment

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DISCLAIMER

CONTENTS

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The project is an initiative of the South West Catchments Council, funded jointly by the Australian Government and the Government of Western Australia under the National Action Plan for Salinity and Water Quality.

SUMMARY

The Department of Agriculture and Food, Western Australia (DAFWA) was commissioned by the South West Catchments Council (SWCC) to set resource condition targets for land salinity and native vegetation in the portion of the South West Natural Resource Management Region with less than 600 mm mean annual rainfall. In the South West we believe that **realistic** and **achievable** targets can only be set by involving the landholders who will need to make the changes on their land to cope with and manage salinity.

The Department of Agriculture and Food (Keipert et al. in prep.) developed a process involving two-half day workshops which combined the latest scientific information and simple models with local knowledge of salinity and its management to set long term targets for salinity and native vegetation.

The title for the first Upper Crossman catchment workshop was:

Linking science with local aspirations

At this workshop, an hydrologist from the Department provided the latest information on current and future groundwater and salinity levels as well as the likely impact of a range of recharge management scenarios. All the available management options were discussed and the group nominated three management options for further modelling to be presented at the second workshop.

The title for the second Upper Crossman catchment workshop was:

Setting targets for action

The results of the modelling were presented and the impacts of the different management options discussed. The group considered these options and then finalised the following resource condition targets for the Upper Crossman catchment.

The landholders in Upper Crossman agreed to the following resource condition targets:

- Manage salinity so that no more than 6 per cent of the Upper Crossman catchment is affected by salinity in 2028. (Landholders estimated that 4 per cent of the catchment is currently affected by salinity and the full-risk by 2028 was estimated as 6 per cent of the catchment.)
- Protect the assets of productive farmland, remnant vegetation and water resources to ensure no net loss in production.

1. INTRODUCTION

The South West Catchments Council (SWCC) commissioned the Department of Agriculture and Food to set land salinity and native vegetation resource condition targets in seven catchments in the portion of the South-west region with mean annual rainfall of less than 600 mm. This followed the successful completion of a pilot project that involved five catchments in 2006. These targets were a requirement for investment under its regional natural resource management (NRM) strategy. The project is an initiative of the South West Catchments Council funded jointly by the Australian Government and the Government of Western Australia under the National Action Plan for Salinity and Water Quality.

The project’s Community and Stakeholder Reference Group initially identified 31 catchments to test a process for linking science with local aspirations and knowledge in setting realistic resource condition targets. The list of 31 catchments was re-evaluated and seven catchments in the low and medium rainfall areas of the Blackwood and Murray River basins were invited to collaborate with the Department of Agriculture and Food in setting measurable targets for dryland salinity.

The Upper Crossman catchment group was invited to take part in the target setting workshops because of the group’s history of active involvement in Landcare. The process was assisted locally by Natalie Lees, Natural Resource Management Officer (NRMO) for the Shires of Narrogin and Williams.

1.1 Upper Crossman catchment

The Upper Crossman catchment covers approximately 36 690 ha and is situated less than 8 km northwest of Williams. The lower three quarters of the Upper Crossman catchment falls within the Eastern Darling Range Zone and the upper portion falls within the Southern Zone of Rejuvenated Drainage (Schoknecht et al. 2004; Department of Agriculture and Food, 2008). The upper catchment is characterised by long undulating hillslopes with gravelly ridges and crests. Breakaways and areas of rock outcrop are extremely rare. The valleys in the upper portion of the catchment are narrow and broaden very little at the lower end of the catchment. The natural drainage is well-incised, particularly in the lower portion of the catchment. Basic descriptions of the soil-landscape units mapped in the Upper Crossman catchment are presented in Appendix 4 and further information is presented in the Avon Hotham Catchment Appraisal report (Murphy White 2005).

The long-term mean annual rainfall is 500 to 575 mm. An analysis of rainfall trends for the study area was performed by Raper et al. (in prep.). It showed that the mean annual rainfall for Williams has fallen from 555 mm per annum in the period up to 1975 to 496 mm per annum for the period 1976 to 2005, a reduction of 11 per cent. Furthermore, post-1975 growing season rainfall (May to October) for Williams is 377 mm compared to 450 mm pre-1975, a reduction of 16 per cent. Similarly, at Wandering the post-1975 rainfall has fallen to 542 mm/yr, a reduction of 15 per cent relative to the pre-1975 figure of 635 mm. Post-1957 growing season rainfall at Wandering has fallen 19 per cent, from 525 mm/yr to 424 mm/yr.

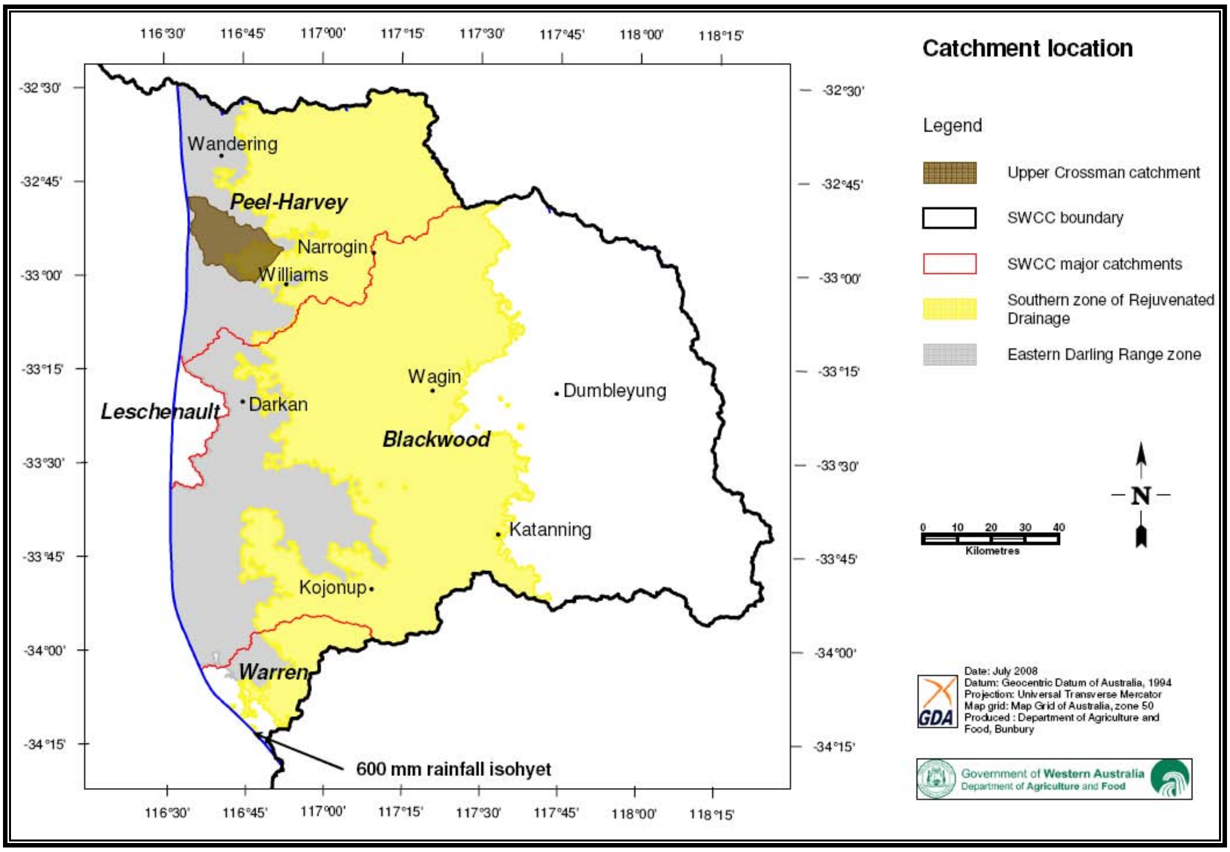

Figure 1 Location of the Upper Crossman catchment within the South West Natural Resource Management Region.

1.2 Workshop aims

The aims of the workshops were to:

- Determine landholders' perceptions of the salinity risk to the catchment **and their aspirations** for its management (that is, to incorporate landholder views on the likely future extent of salinity on their properties and in their catchment)
- Present catchment information on **current salinity impacts, trends for the future** and **an assessment of the likely impact of two levels of salinity management effort**.
- Identify **salinity management options** of interest to the landholders.
- Provide **an estimation of the likely impact of the salinity management options favoured by the landholders**.
- Agree to a **catchment resource condition target (20 year) for land salinity** and **native vegetation**.
- Identify and prioritise five-year management action targets.

1.3 Current salinity—local view

The landholders identified the salinity status of their properties. It was agreed that the works implemented had had substantial impact over the last ten years, however there were signs that salinity was still an issue on individual properties within the catchment.

1.4 Local aspirations

At the first workshop, the landholders' aspirations for the control of salinity in their catchment were explored using a continuum (Figure 2). The following criteria were used:

- **Full risk**—Allowing salinity to increase with no additional intervention (do nothing scenario).
- **Containment**—Keeping salinity within the catchment to current levels.
- **Full recovery**—Returning currently saline land back to previous level of agricultural production.

Full risk	Containment	Full recovery
	↑ ↑ ↑ ↑	↑ ↑ ↑ ↑

Figure 2 Continuum of landholder initial aspirations, each arrow represents one landholder's aspirational target for salinity management.

Creekline identified for revegetation

2 CURRENT SALINITY IMPACTS AND FUTURE TRENDS

During the first workshop, the landholders were presented with regional and catchment-scale information on groundwater trends, salinity status and future salinity risk. The limitations and scale issues associated with each information source were discussed and the landholders were then invited to provide feedback from their local knowledge.

2.1 Groundwater trends

The regional groundwater trends have been analysed for each of the main soil-landscape zones in the low and medium rainfall zones of the South West NRM region. Upper Crossman catchment falls within two main soil-landscape zones, the Eastern Darling Range Zone and the Southern Zone of Rejuvenated Drainage and, due to the lack of any groundwater data for the catchment, these regional trends were the only groundwater data that could be presented to the group. The groundwater trends for the zones are presented in Table 1(a) and (b). Although a small majority (22 of 42) of bores in lower slope and valley floor positions indicate that some watertables have reached equilibrium, a significant number (18 of 42) indicate that groundwaters in areas of salinity risk are still rising at rates of between 0.05 m/yr and 0.25 m/yr.

Table 1 **(a): Regional groundwater trends (Raper et al. in prep.)**

Landscape position	Average trend	Eastern Darling Range Zone		
		Number of bores	Average rate of change (m/yr)	Mean depth to water (m)
Upland flat	*Rising*	10	0.40	-1.5
	Equilibrium	1	-	-0.7
Upper slope	*Rising*	13	0.30	-12.2
	Equilibrium	1	-	1.6
Mid slope	*Rising*	7	0.45	-7.4
Lower slope	*Rising*	5	0.25	-1.0
	Equilibrium	1	-	0.1
Valley floor	*Equilibrium*	3	-	-0.1

Table 1 **(b): Regional groundwater trends (Raper et al. in prep.)**

Landscape Position	Average trend	Southern Zone of Rejuvenated Drainage		
		Number of bores	Average rate of change (m/yr)	Mean depth to water (m)
Upper slope	*Rising*	11	0.40	-9.7
	Equilibrium	4	-	Dry
Mid slope	*Rising*	21	0.20	-5.3
	Equilibrium	5	-	-4.5
Lower slope	*Rising*	11	0.15	-1.4
	Equilibrium	10	-	-1.4
	Falling	1	-0.05	-1.9
Valley floor	*Rising*	2	0.05	-0.3
	Equilibrium	8	-	-0.6
	Falling	1	-0.10	-0.9

2.2 Current salinity impacts

The Land Monitor project used high resolution digital elevation data and remotely sensed vegetation health data to map salt-affected land and to produce an estimate of the maximum possible future extent of salinity in the south-west agricultural region (McFarlane et al. 2004). Land Monitor (2001) estimated that 450 ha (1 per cent) of the Upper Crossman catchment was salt-affected in 1998 (Evans 2001) with 5,600 ha (15 per cent) remnant vegetation in the catchment (Figure 3).

The Land Monitor estimate of current salinity has limitations that can affect the precision of the mapping. The reported accuracy of the Land Monitor salinity mapping for the eastern zone of the Collie-Pemberton Landsat scene, within which Upper Crossman sits, was 99 per cent for bare saltland but only 70 per cent for marginally saline land (Evans 2001). From previous experience it was realised that Land Monitor significantly underestimated the extent of salinity as it highlighted only the most severely degraded areas and did not include saline areas covered in samphire. At workshop 1, landholders agreed that Land Monitor underestimated the extent of current salinity, but also pointed out that some current salinity had appeared since 1998 and could therefore not be detected during the Land Monitor project. The average rate of expansion of salt-affected land, as mapped by Land Monitor within the Williams Shire between 1990 and 1998, was 49 per cent or 5 per cent per annum (Evans 2001). These rates of expansion of salt-affected land cannot be used as a direct indication of the likely rate of expansion in the Upper Crossman catchment because, unlike a catchment, a shire is an administrative area. The landholders were given the opportunity to mark areas that they identified as currently salt-affected over the Land Monitor salinity map and any discrepancies were noted. They estimated that salinity currently affected 4 per cent of the catchment area (1 460 ha).

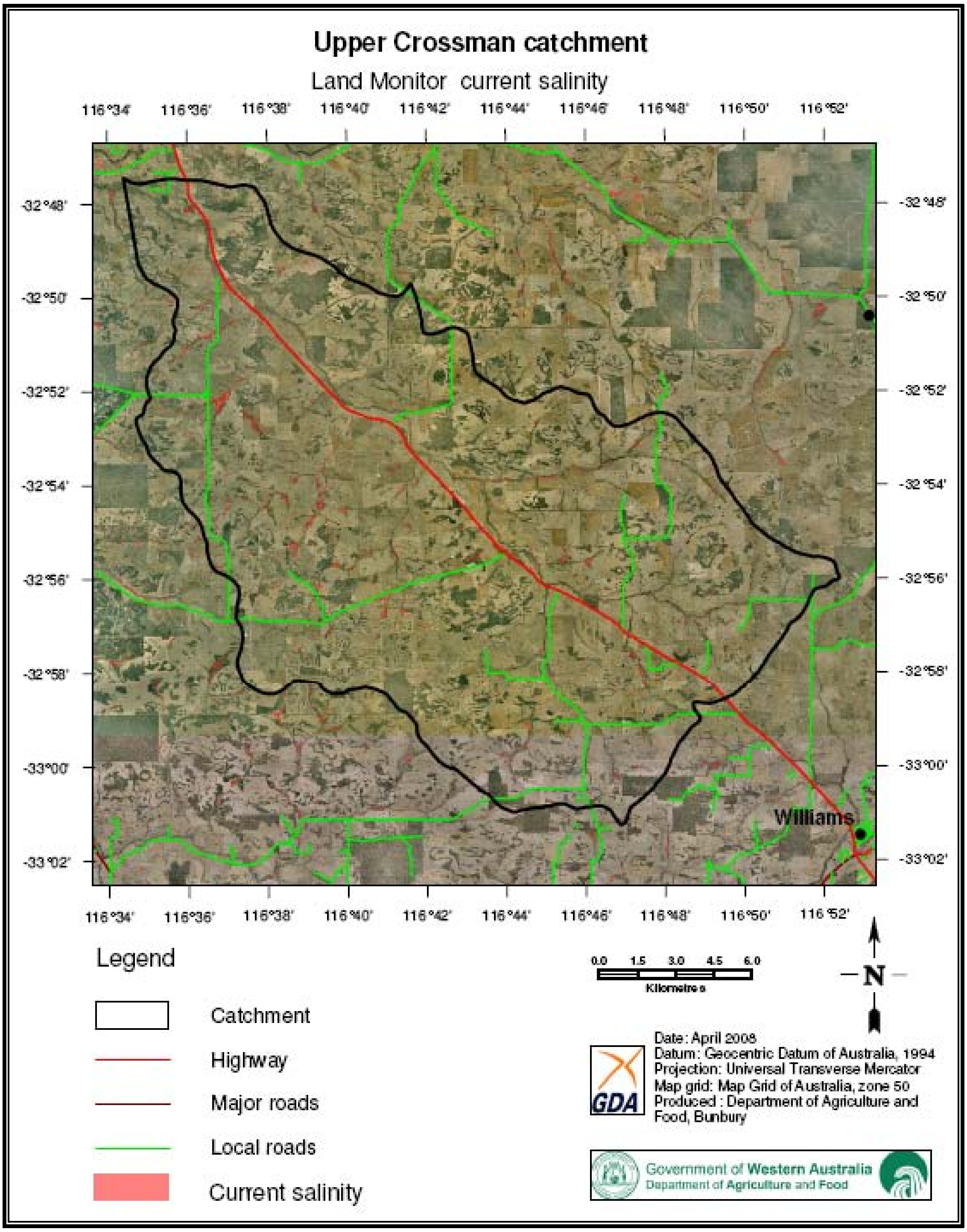

Figure 3 Current salinity in Upper Crossman (Land Monitor 2001).

2.3 Valley floor hazards

Salinity hazard is best thought of as an area of land, usually on a valley floor, where the watertable may approach the ground surface at some future time and give rise to dryland salinity. Valley floor hazard, from the Land Monitor (2001) information for low-lying areas, indicates areas which have the highest risk of waterlogging, flooding, shallow groundwater and salinity (Figure 4).

It is **important to note** that not all these areas will become saline. Variations in topography and soil type are critical factors in determining their susceptibility to salinity. Furthermore, the valley floor hazard mapping does not imply any particular time-frame for the realisation of salinity risk. It can only therefore be used to inform an estimate of salinity risk required to assist in the setting of a 20–year resource condition target.

Land Monitor used digital elevation modelling to derive valley floor hazard. This was reported as the area of valley floor within a specified elevation of the main streamline. Table 2 presents this information as cumulative areas at four classes: 0–0.5 m; 0–1.0 m, 0–1.5 m and 0–2.0 m. The areas in the 0–2.0 m class are almost certainly an overestimate of the salinity hazard for the Upper Crossman catchment. The 0–0.5 m class offers a better estimation of the area at risk of becoming saline if land use remains largely unchanged (McFarlane et al. 2004).

Given the current extent of salt-affected land in the catchment, the reported rates of groundwater rise and their local knowledge, the landholders initially estimated that 4 per cent of the catchment is likely to be salt-affected in 2028, if no further action is taken. They later revised this estimate to 6 per cent of the catchment at the second workshop.

Table 2 **Valley floor hazards in Upper Crossman (Source: Land Monitor 2001)**

Upper Crossman	Total area (ha)	% of catchment	Remnant vegetation (ha)	% of catchment	% of remnant vegetation
Catchment	36 665		5 595	15	-
Land Monitor valley floor hazard at different elevations above the main stream line					
0–0.5 m	3 899	11	816	2.2	14.6
0–1.0 m	4 785	13	914	2.5	16.3
0–1.5 m	5 109	14	948	2.6	16.9
0–2.0 m	5 118	14	949	2.6	17.0

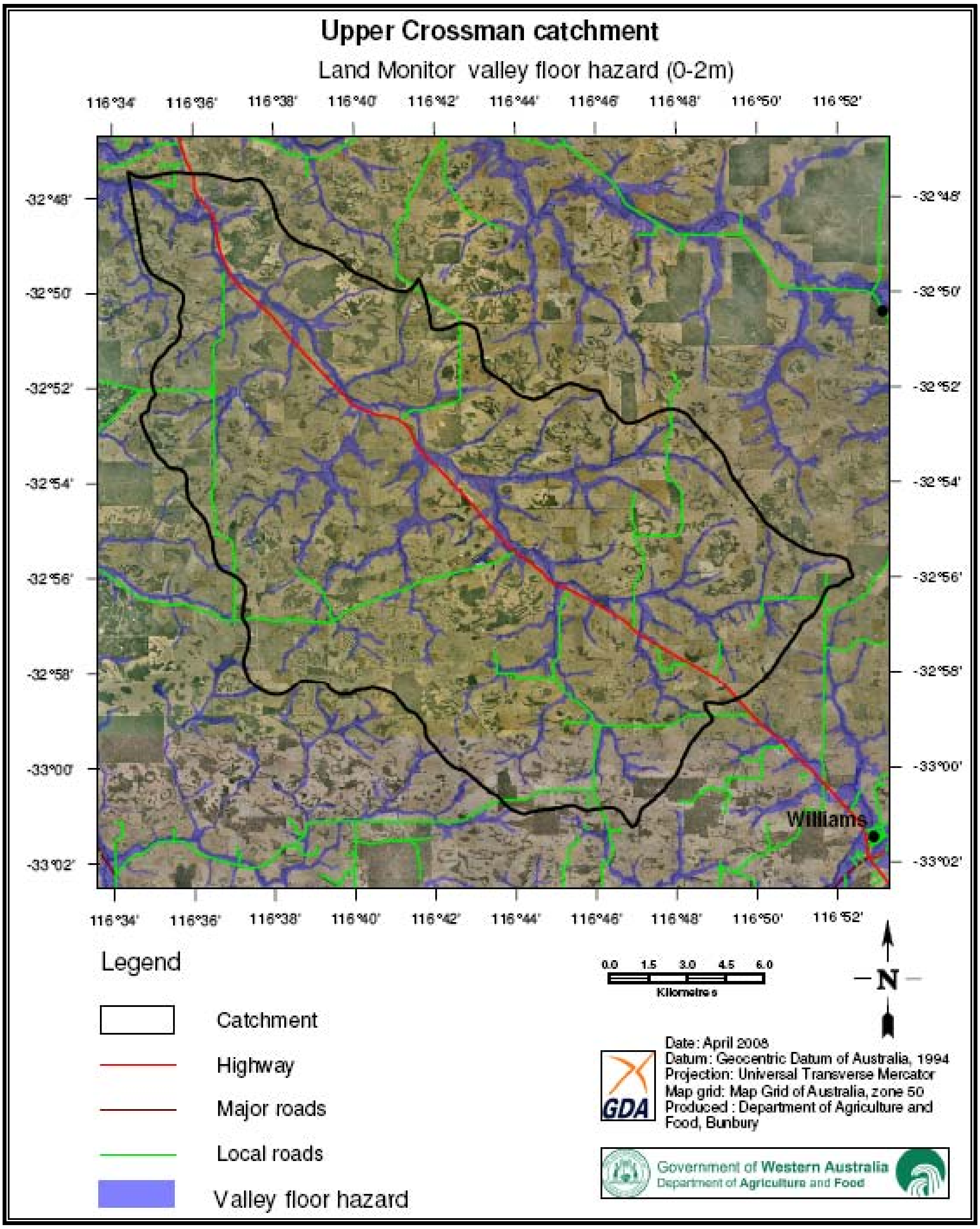

Figure 4 Valley floor hazard in Upper Crossman (Class 0–2 m Land Monitor 2001).

2.4 Predicted impact of recharge reduction strategies

The Flowtube model (Argent 2005) was used to assess the likely impacts of three levels of recharge control on shallow watertables, and therefore salinity risk, for all catchments involved in the project. Flowtube is a simple two-dimensional model which simulates the position of the watertable over time along a groundwater flow line, either down a hillslope or down the main drainage line of the catchment. A limitation of this type of model is that the proportions of the catchment with shallow groundwater for different scenarios must be estimated from the length of the flow line saturated. However, because the model simulates the position of the watertable through time, an estimate at the end of the 20–year time frame required for this exercise is possible.

There are no groundwater data available for the Upper Crossman catchment so modelling could not be done. The East Yornaning catchment, located 37 km east of Upper Crossman, was used as a case study. The model predicted that reducing recharge by 25 per cent, 50 per cent or 75 per cent across the catchment would have a limited impact on the area at risk from shallow watertables and thus the area at risk of becoming salt-affected (see Table 3). Note that percentage area figures presented in Table 3 are quoted to one decimal place. This is to show the very small differences in the areas calculated and is not a reflection of the accuracy of the modelling.

Table 3 **Predicted salinity risk under three levels of recharge control for the East Yornaning case study catchment**

Scenario	Percentage of catchment with shallow watertable
Current practice	15.7
25% recharge reduction	15.6
50% recharge reduction	15.2
75% recharge reduction	14.7

3. SALINITY MANAGEMENT OPTIONS

The Upper Crossman landholders identified works that they had undertaken over the last 10 years to manage salinity. This is shown in the timeline in Figure 5. They also identified management actions that they were considering implementing to manage salinity in the future. These are captured in the mind-map in Figure 6. The mind-map shows the key areas for action (e.g. trees) and shows the linkages between some of the options identified.

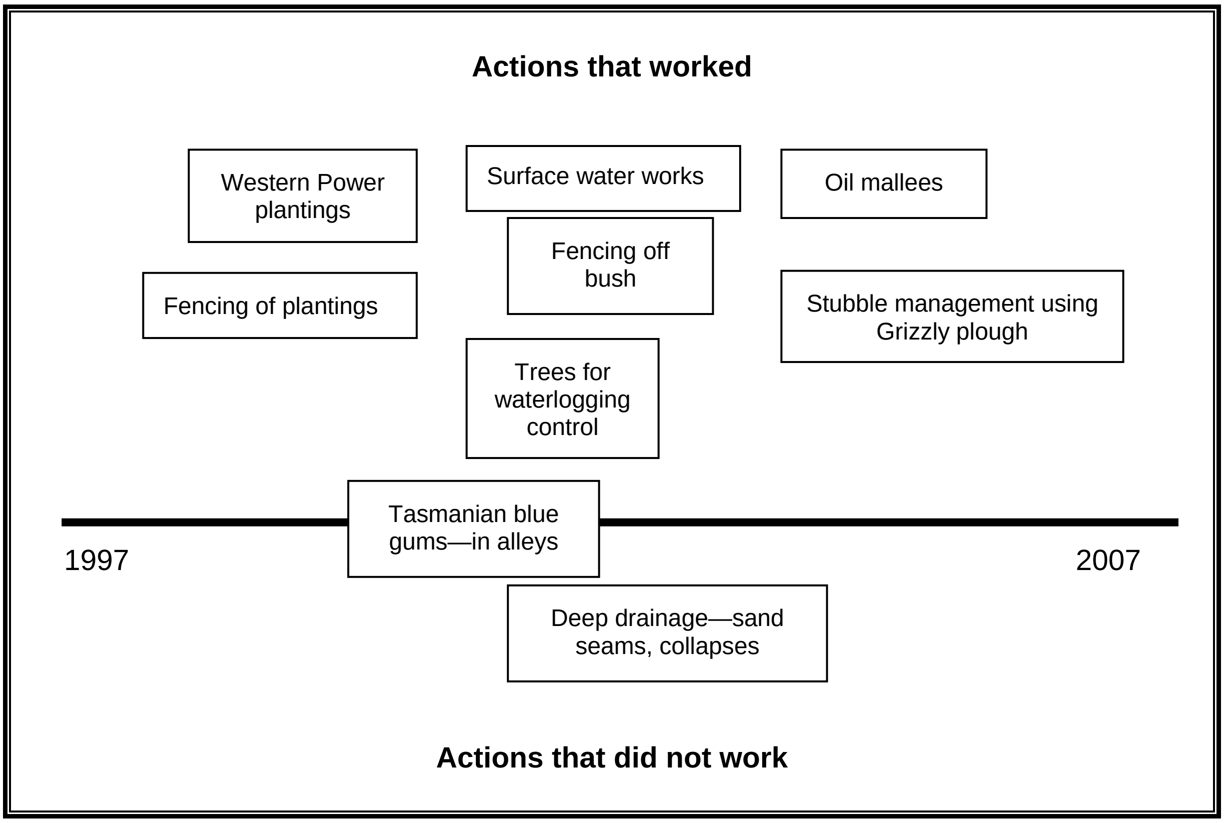

Figure 5 Works undertaken in Upper Crossman catchment.

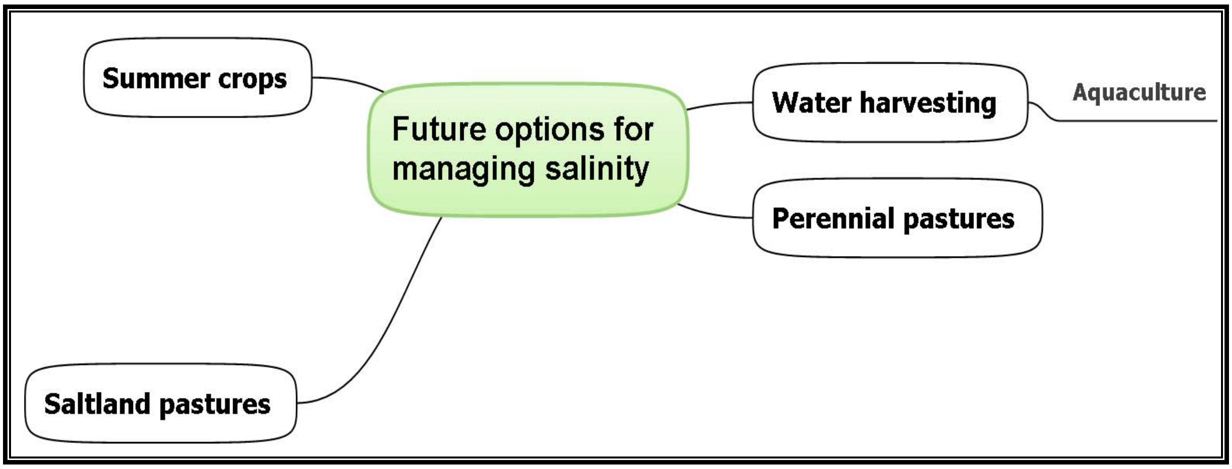

Figure 6 Potential options for managing salinity in the Upper Crossman catchment.

4. MODELLING

The landholders chose three scenarios from the salinity management options identified in Figure 6 to model their impact on salinity risk. The most appropriate modelling tool available for the simulation of each scenario was chosen, the choice being dependent on the nature of the management option to be simulated and the availability of data to support the modelling. Case studies from other catchments were used where no data were available for the Upper Crossman catchment. The following management options were nominated:

- Perennial and saltland pastures
- Water harvesting
- Deep drainage.

4.1 Scenario 1 ~ Perennial and saltland pastures

The Flowtube model was used to simulate the likely outcome of two recharge reduction oriented perennial pasture options and a saltbush based option for the lower portion of the catchment. As with the recharge reduction scenarios presented above, the East Yornaning catchment was used as a case study. Two perennial pasture scenarios were modelled; a catchment wide 50:50 perennials to annuals mix to represent an aggressive replacement of annual species with perennials and a 20 per cent lucerne scenario to represent a more conservative, economically defensible perennial strategy. The third scenario was the planting of saltbush on all lower slope areas not already vegetated with woody perennials.

4.1.1 Assumptions

- East Yornaning catchment data are applicable to Upper Crossman.
- Perennial pastures and saltbush are healthy and effective in reducing recharge.

4.1.2 Impact

Different scenarios for perennial pastures and saltbush were modelled and the results are summarised in Table 4.

Table 4 **Vegetation Scenarios (East Yornaning data used)**

Scenario	Percentage of catchment with shallow watertable
Current practice	15.7
Perennials 50:50	15.6
Lucerne 20%	15.7
Saltbush	15.6

4.2 Scenario 2 ~ Water harvesting (surface water management)

The MODFLOW distributed groundwater flow model (McDonald and Harbaugh, 1988) was used to simulate the likely outcome of surface water management on lower slopes and valley floors. The model was setup for the 8 600 ha Queerfellows Creek catchment, about 60 km south-east of Upper Crossman, and entirely in the Southern Zone of Rejuvenated Drainage. The Queerfellows modelling was used as a case study because it provided explicit information on the impact of surface water management options, designed and implemented by landholders in a catchment with some soil and morphological similarities. The mean annual rainfall in the Queerfellows Creek catchment is 425 to 450 mm. The Queerfellows Creek landholders included 34.2 km of surface water control structures and drains on their farm plans in 2000 and the impacts of these planned works were simulated. Most of the planned works have now been installed for several years. Simulations were also performed for surface water control structures installed at twice and three times the density indicated on the farm plans (Keipert et al. in press). The model predicts the equilibrium depth to groundwater given annual recharge and the impacts of drainage; the results are therefore not time-bound and the time required to reach a new equilibrium is not determined.

4.2.1 Assumptions

- Queerfellows Creek data is applicable to Upper Crossman.
- Banks and drains at twice and three times the density specified in the Queerfellows Creek farm plans.
- Recharge is reduced by 50 per cent for 100 m downslope of drain.

4.2.2 Impact

A range of scenarios are presented for surface water control (Table 5). Modelling predicted that the area at risk from shallow watertables would be reduced from 26 per cent to 23 per cent of the catchment with a doubling or trebling of the length of surface water management structures as proposed on the farm plans. Trebling the length of surface water management structures resulted in a predicted area at risk not significantly different to a doubling of the length of surface water management structures because a doubling covered almost all of the high risk areas. It should be noted that, because an equilibrium model was used, the time required to reach the estimated area with shallow groundwater is not determined and may be different under each management option modelled.

Table 5 **The impact of surface water management with shallow watertables in Queerfellows Creek catchment**

Scenario	% of catchment with shallow watertables
Base case	26
Farm plans—double surface water control	23
Farm plans—triple surface water control	23

Surface water control has two main benefits in relation to salinity management. The first is recharge reduction, which is simulated in the MODFLOW model, and second, a reduction in waterlogging and inundation which cannot be explicitly modelled. Reduction in waterlogging will have a positive impact on the surface condition and productivity of the area treated; this is not quantifiable and is therefore not reflected in the results presented in Table 5.

4.3 Scenario 3 ~ Deep drainage

The landholders requested that, rather than perform a quantitative assessment of deep drainage for the Upper Crossman catchment that results of the Engineering Evaluation Initiative drainage trial at Beynon Road (Cox and Tetlow, 2008) be presented. The Beynon Road drainage network consists of four lateral drains discharging to a collector with outlet to a salt-affected natural creek. The collector drain is 3 m deep at the upslope end and grades to 2 m deep at the discharge point. The laterals were either 2 m or 3 m deep and three of them run parallel about 190 m apart. All drains were levied to prevent surface water entering the drains in an uncontrolled manner that may cause erosion. An annotated aerial photograph showing the layout of the Beynon Road drainage trial and cross-sections shown the groundwater response are presented in van Wyk and Raper (in prep.).

Cox and Tetlow (2008) show that the lateral drains are far more efficient at removing stored groundwater from the profile than the collector drain and that drain efficiency is determined by depth and drainage density. That is, the parallel lateral drains are more efficient because a groundwater gradient is established toward each drain with the maximum impact on groundwater levels between them. The influence of collector drain on groundwater levels may extend to as much as 350 m from the drain but the magnitude of the impact is minimal beyond about 70 m from the drain.

Read and Petersen (2006) suggest that, to be economically viable, a deep drainage system needs to have a significant impact on groundwater levels about 200 m from the drain. Analysis of the areas at risk from salinity in the Upper Crossman catchment indicated that most of the valley floor areas at risk were less than 200 m wide (see Figure 4).

5. ASSETS AND TARGETS

5.1 Assets at risk to salinity

The Upper Crossman landholders nominated that in addition to agricultural land the following assets are at risk or are already affected by salinity:

- Remnant vegetation on private bushland
- Water supply—dams
- Peel inlet (downstream).

5.2 Upper Crossman catchment targets

The landholders in Upper Crossman agreed to the following resource condition targets:

- Manage salinity so that no more than 6 per cent of the Upper Crossman catchment is affected by salinity in 2028. (Landholders estimated that 4 per cent of the catchment is currently affected by salinity and the full-risk by 2028 was estimated as 6 per cent of the catchment.)
- Protect the assets of productive farmland, remnant vegetation and water resources to ensure no net loss in production.

6. FUTURE OPTIONS TO MANAGE SALINITY AND NATIVE VEGETATION

The landholders identified salinity management options that they consider appropriate for them to implement in the short to medium term and these are summarised in Appendix 3. Further Management Action Targets (MATs) were discussed during workshop 2 and then prioritised according to the group's and/or individual's ability to implement the action and the potential impact on the likelihood of achieving their agreed land salinity resource condition target (Figure 7).

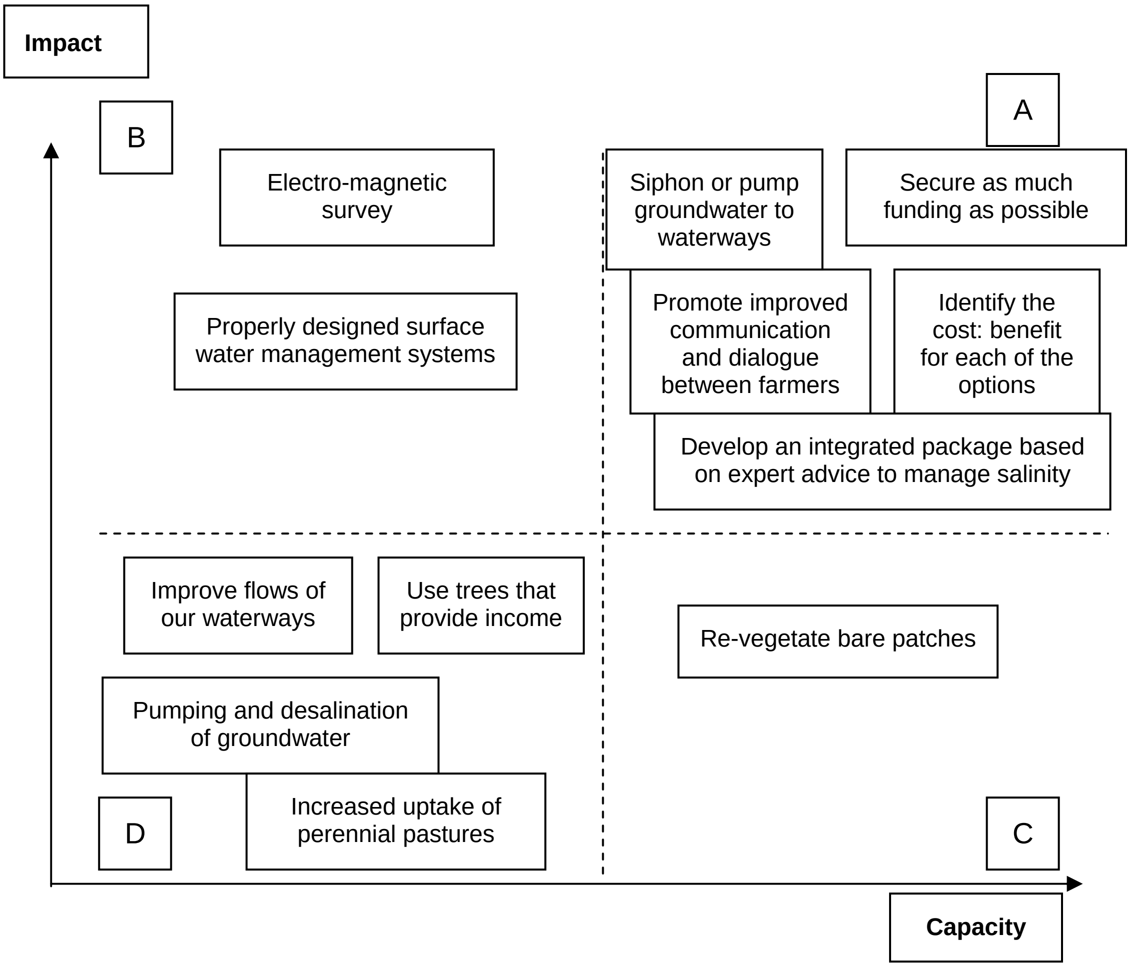

Figure 7 Prioritised management actions based on impact of action and capacity to implement.

Each of the nominated management actions was discussed to determine if it will have a low or high impact on achieving their agreed land salinity resource condition target. The group then determined if members had a low or high capacity to implement the action. This determined the quadrant in which the management action was placed (A, B, C or D). The quadrant in which an action is placed determines its priority and timeline for implementation.

A = Immediate (0–3 years) action (high impact and high capacity).

B = Longer or medium-term action (needs more resources—high impact and low capacity).

C = Short-term action (a small win can help build confidence—low impact and high capacity).

D = Needs to be reviewed in future to see if priority or circumstances have changed (low impact and low capacity).

7. CONCLUSION AND RECOMMENDATIONS

The Upper Crossman landholders were presented with information on the extent of salt-affected land in the catchment derived from remotely-sensed data under the Land Monitor project. The data suggested that over 450 ha (1 per cent) of the catchment was salt-affected in 1998. The landholders mapped currently salt-affected land and determined that 1 450 ha (4 per cent) of the catchment is currently affected, the difference between the Land Monitor estimate and that made by the landholders is made up of saline areas not identified by the Land Monitor process and an expansion of the salt-affected area in the intervening decade. Analysis of the Land Monitor data shows that although the area affected by salinity in the Williams shire was very small (0.6 per cent in 1990), the rate of expansion was very high (5 per cent per annum) between 1990 and 1998, and Upper Crossman is typical of this.

The Land Monitor valley floor hazard mapping suggests that the maximum area at risk from salinity within the Upper Crossman catchment is 11 per cent, but this estimate is not time-bound and the landholders estimated that 6 per cent of the catchment is likely to be salt-affected within 20 years if no further action is undertaken.

The Upper Crossman landholders nominated two scenarios for modelling to assist them in setting time-bound, achievable resource condition targets for land salinity, these were:

- perennial and saltland pastures;
- water harvesting.

The landholders also asked for information on the outcomes of the Engineering Evaluation Initiative deep drainage trial at Beynon Road, even though they did not consider deep drainage a high priority for the Upper Crossman catchment.

The Upper Crossman catchment landholders set their 20–year, land salinity resource condition target to contain the extent of salt-affected land to 6 per cent of the catchment area which is equal to their best estimate of the area at risk if no further management action were to be taken. They chose this target for land salinity because they perceived that the area was small in relative terms and that their longer-term interests were best served by continuing with small-scale action and planning for more interventionist management in the longer term.

The modelling of potential salinity management actions and all other information available suggested by the catchment group (Section 4) shows that the resource condition target agreed to by the landholders is achievable.

The primary focus of the Upper Crossman landholders over the next 20 years was to minimise degradation on land that did become salt affected, protect remnant vegetation and water resources to ensure no net loss of production. They prioritised the following salinity management actions in support of their agreed land salinity resource condition target:

- Develop an integrated package based on expert advice to manage salinity.
- Identify the cost to benefit ratio for each option.
- Promote improved communication and dialog between farmers.
- Siphon or pump groundwater to waterways.
- Secure as much funding as possible.
- Electro-magnetic survey.
- Properly designed surface water management systems.

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9. APPENDICES

Appendix 1. Workshop dates and attendees

Workshop 1: Linking science with local aspirations

Thursday 17 April 2008. Williams Telecentre

Attendees

Landholders: Bronny Harding, Jeanette Liddelow

Support team: Paul Raper, Leon van Wyk, Natalie Lees and Andrew Huffer

Workshop 2: Setting targets for action

Thursday 19 June 2008. Williams Telecentre

Attendees

Landholders: Bronny Harding, Jeanette & Brian Liddelow, Jacky Chadwick, Mark Fowler, Kevin Martin, Richard Johnstone, Libby Fowler and Helen Williamson

Support team: Paul Raper, Leon van Wyk, Natalie Lees and Andrew Huffer

Appendix 2. Workshop feedback

What was worthwhile?	What should be changed?
▪ The prioritisation session. Provided a focus on the on-ground and practical components. ▪ Good to find out from the ‘experts’ what are the best actions to focus on and what should be avoided.	▪ Still much of the same approaches that we’ve been using for the last 20 years. ▪ Provide the data, information and statistics before the workshop. ▪ Would be good to have more discussion on what has and has not worked. ▪ Process run in November to align with tree ordering.

Appendix 3. Future methods of managing salinity in the Upper Crossman catchment

	Management options	Name	Please specify (type, approx when)
1.	**Deep-rooted perennial species to increase water use**		
•	Woody shrubs and trees	Mark Fowler Bronny Harding Libby Fowler	
•	Commercial tree crops (e.g. pines, oil mallees)	Kevin Martin	Thinking about the option
•	Land conservation (add to existing remnant veg)	Jacky Chadwick	Trees along creeklines
•	Forage crops (e.g. tagasaste)	Jacky Chadwick	Saltbush
2.	**Plant crops and Pastures to increase water use**		
•	Increase productivity of saline lands (e.g. balansa, tall wheat grass, or saltbush)	Jacky Chadwick Mark Fowler Bronny Harding Libby Fowler	Would like to try Balansa, tall wheat grass, or saltbush Saltbush
•	Perennial pastures (e.g. lucerne)	Jacky Chadwick Mark Fowler	Would like to try
•	Summer crops	Jacky Chadwick	Would like to try
•	Improved agronomy of annual pastures and crops	Jacky Chadwick Mark Fowler Richard Johnstone Libby Fowler	Would like to try Reduce acidity and retain crop residue
3.	**Collect, reuse and dispose of surface water**		
•	Surface earthworks (e.g. grade backs, inceptor banks, W-drains)	Jacky Chadwick Kevin Martin	Improve existing banks Continue to construct new surface drains
•	Other strategies (e.g. woody perennials).		
4.	**Drain or pump, reuse and disposal of groundwater**		
•	Deep drains	Jacky Chadwick Mark Fowler Kevin Martin	To dry out waterlogged areas Investigating the option
•	Pumps	Mark Fowler	
•	Aquaculture	Jacky Chadwick	Make use of excess water
•	Siphons and relief wells	Mark Fowler	

	Management options	Name	Please specify (type, approx when)
5.	**Protect and manage remnant native vegetation**		
•	Protective fencing	Jacky Chadwick Mark Fowler Bronny Harding Richard Johnstone Libby Fowler	Fence salt lands after planting saltbush/trees Creeklines and native vegetation
•	Rehabilitation	Jacky Chadwick Richard Johnstone	Get rid of pigs
•	On-going management (e.g. weed control)	Kevin Martin Richard Johnstone	

Appendix 4. Soil-landscape units of the Upper Crossman catchment (DAFWA, 2008)

Mapping unit	Area (ha)	Proportion of catchment (%)	Landform	Soils
253MuCK	8 120	22	Shallow minor valleys (5–20 m) with gentle (3–10 per cent) to sometimes steep (30–40 per cent) side slopes.	Loamy gravels, duplex sandy gravels, brown deep loamy duplexes, brown loamy earths, deep sandy gravels and wet and semi-wet soils (sometimes saline)
253MuCKr	1 050	3	Shallow minor valleys (5–20 m) with gentle (3–10 per cent)to sometimes steep (30–40 per cent) side slopes with common (15-20 per cent) rock outcrops	Loamy gravels, bare rock, stony soils, brown deep loamy duplexes, pale shallow sands, duplex sandy gravels and loamy earths
253MuDW	920	2	Plateau remnants; large areas of undulating and gently undulating laterised upland	Loamy gravels, duplex sandy gravels, shallow gravels and deep sands
253MuNO	6 670	18	Plateau remnants; small areas of undulating and gently undulating laterised upland and associated pediments	Loamy gravels, duplex sandy gravels, shallow gravels and deep sandy gravels
253MuNOr	50	0	Small (20–1000 ha) lateritic residuals (mesas) and associated pediments	Bare rock, stony soils, loamy gravels, red shallow loams and brown loamy earths
253QdBK	1 210	3	Valley floors and associated footslopes surrounded by gently undulating rises and low hills	Yellow/brown deep sandy duplexes, brown deep loamy duplexes and wet and semi-wet soils (often saline)
253QdMN	7 070	19	Generally moderate irregular valley slopes	Brown deep loamy duplexes, yellow/brown deep sandy duplexes, grey deep sandy duplexes, red shallow loams and gravels
253QdMNr	590	2	Generally moderate irregular hill slopes with some steep slopes with common (15–20 per cent) rock outcrops	Bare rock, stony soils, brown deep loamy duplexes and yellow/brown deep sandy duplexes
253QdMNrx	530	1	Generally moderate irregular hill slopes with some steep slopes with many (40–50 per cent) rock outcrops	Bare rock, stony soils and duplex soils
253QdNO	990	3	Plateau remnants; small areas of undulating and gently undulating laterised upland; breakaways	Loamy gravels, duplex sandy gravels and red shallow loamy duplexes
253QdWL	370	1	Moderately to deeply incised valleys	Yellow/brown deep sandy duplexes, brown deep loamy duplexes, grey deep sandy duplexes and wet and semi-wet soils
257DyBK	570	2	Valley floors and associated footslopes surrounded by gently undulating rises and low hills	Yellow brown sandy duplexes (mostly deep), wet and semi-wet soils (sometimes saline) and brown deep loamy duplexes
257DyNB	7270	20	Long gentle and undulating hillslopes and divides	Yellow/brown and grey deep sandy duplexes, brown deep loamy duplexes, sandy gravels and shallow duplexes
257DyNBr	450	1	Long gentle and undulating hillslopes and divides with common (15–20 per cent) rock outcrops	Bare rock, stony soils and yellow/brown and grey deep sandy duplexes
257DyNBrx	50	0	Long gentle and undulating hillslopes and divides with many (40-50 per cent) rock outcrops	Bare rock, stony soils and sandy and loamy duplex soils
257DyNO	790	2	Plateau remnants; small areas of undulating and gently undulating laterised upland; breakaways	Loamy gravels, duplex sandy gravels, shallow gravels and red shallow loamy duplexes