South West Goulburn: Tree Cover for Salinity Management

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SOUTH WEST GOULBURN: TREE COVER FOR SALINITY MANAGEMENT

- Final Report
- 14/09/2004

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Executive Summary

This report documents work undertaken in Part 2 of the South West Goulburn project managed by the Goulburn Broken CMA. Some essential background to the work described here is provided by the Part 1 report, published by the Dept. of Primary Industries in June 2003.

Part 2 of the South West Goulburn project investigates the interpretation of outputs from the catchment models to identify areas where afforestation with native vegetation/trees will bring about an effective long-term reduction in salt load export. Areas suited to afforestation are identified at the scale of the whole South West Goulburn region (approximately 3000 km^2) extending the application of the models of case study areas (Gardiner Creek and Hamilton/Dry Creeks). Refinement and evaluation of the catchment models is also undertaken.

The objectives of the project and the outcomes of the investigation are described below.

Objective 1. To evaluate and explain components of the modelling approach.

There were several questions that arose from the application of the Management of Catchment Salinisation (MCS) model in Part 1 of the project. Firstly, catchment salt load was estimated using the model and using data from stream gauges in neighbouring catchments. The agreement between these estimates was not as good as expected and this is explained as follows: (a) data constraints necessitate a simple catchment characterisation; (b) the conceptualisation of processes is also necessarily simple (e.g. a daily rainfall total is used to estimate runoff generated by storms that may last for a few hours only); and (c) stream salinity measurements have only been recorded in local stream gauges since 1990 and this contributes to the difficulty providing reliable estimates of average annual salt load from stream gauges.

Secondly, the soil profile model indicated little difference in surface runoff between land uses and a large difference between different underlying depth to watertable conditions. The small difference in surface runoff between trees and pasture might initially suggest that trees can only affect stream baseflow in the MCS model. However, the reduced recharge under trees reduces baseflow and also causes the watertable to be deeper in other parts of the catchment that in turn reduces runoff from other land uses.

Lastly, tree planting was not as effective in reducing salt load in the Hamilton/Dry case study area as it was in the Gardiner case study area. This result is caused by differences in topography of the two areas and differences in the depth to watertable underlying the proposed areas of trees. The depth to watertable is an important input to the identification of areas suited to reafforestation across the whole South West Goulburn (Objective 3).

Objective 2. Undertake targetted model sensitivity tests.

The MCS model has two primary component models: (1) a soil profile model, SoilFlux, that uses a daily timestep, and (2) a groundwater model (MODFLOW) that models average annual fluxes and is used in steady state mode for this project. Catchment management options for reducing salt load export are investigated through the integration and application of these components.

The sensitivity of MCS model outputs to selected model inputs is evaluated under Objective 2. A summary of findings follows.

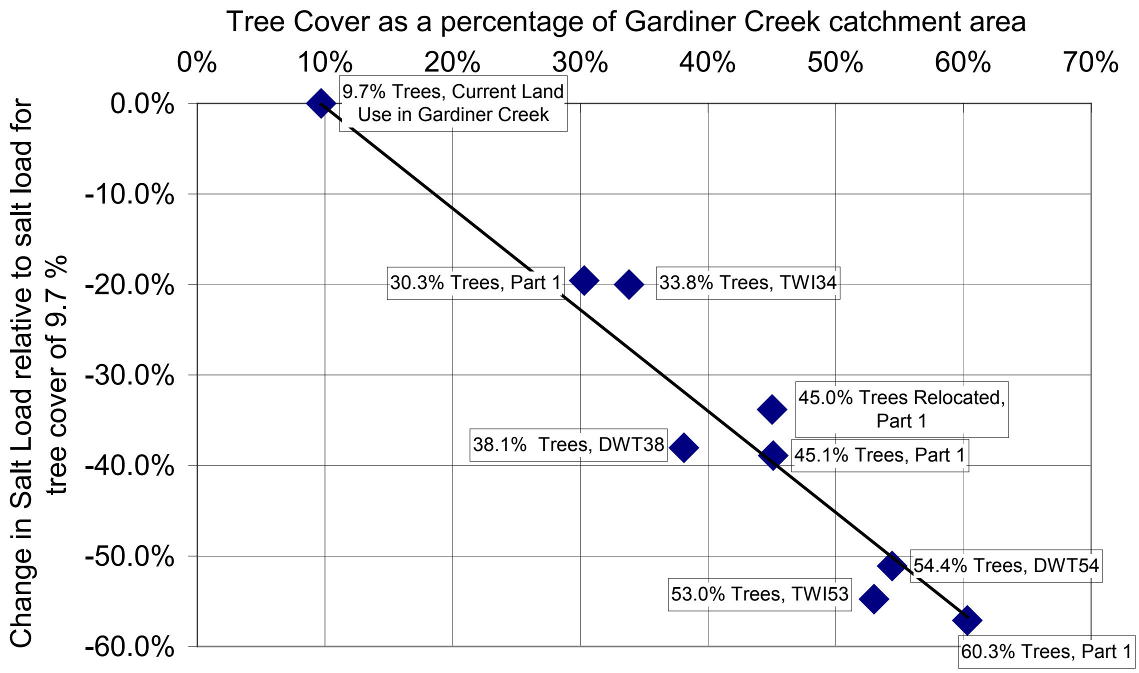
- the inputs to the salt wash-off module in the soil profile model can be adjusted to allow further calibration of salt load carried in surface runoff (under Objective 1 we investigated the lack of agreement between the independent estimates of this salt load component)
- the soil water balance of trees is affected by the representation of trees in the soil profile model although differences in tree water use due to model inputs are reduced by salt accumulation in the tree root zone
- changing the representation of priority areas of high recharge in the groundwater models has little effect on the overall catchment salt and water balance
- improvements in the representation of streams produce a more realistic model of the watertable surface around stream beds, and this contributes to an improved catchment water balance. It also reduces the difference in effects of trees planted alongside streams and trees planted away from streams (the large differences noted in Part 1 between the 45 % trees and 45 % trees – relocation scenarios are now reduced).
- groundwater model boundary conditions at the model edges are found to have little influence on the modelled effect of trees on salt load
- adopted groundwater salinity has a strong effect on modelled salt load.

Objective 3. Identifying Areas for Native Vegetation/Trees

This project develops an approach to identifying locations for afforestation across the South West Goulburn that would produce long term salt load reductions. The spatial data sets input to the approach are: existing tree cover; depth to watertable (DWT); topographic characteristics (topographic wetness index, TWI); and characteristics of groundwater recharge. (The calculation of TWI is explained within the report.)

Many combinations of rules for using the spatial data sets were considered. For example, rule combinations that were strongly influenced by either DWT or TWI were tested on the case study areas. The tree locations identified by these two rule combinations and tree cover scenarios used in Part 1 of the project were compared in terms of their effect on stream flow and salt load. Figure i below is an example of this analysis.

Figure i. Gardiner Creek case study area: change in salt load vs tree cover. The line shown is the linear regression line that passes through the point representing current conditions.



Stream flow and salt load are both reasonably well characterised by a linear relationship with tree cover in the case study areas. A perfectly linear relationship would suggest that the effects of trees are independent of location in the catchment. However some variation between tree cover scenarios is noted indicating that, for the same percentage tree cover, different approaches to locating trees in a catchment may have different effects on salt load. Salt load reductions in Hamilton/Dry were slightly lower than in Gardiner Creek reflecting topographic and hydrogeological differences between the case study areas.

The effect of different tree cover scenarios at the scale of the South West Goulburn can be estimated using the approximate linear relationships between stream flow and tree cover and between salt load and tree cover. Four scenarios of tree cover across the SWG are considered in this project: 69 % tree cover; 57 % tree cover; 50 % tree cover; and 33 % tree cover. Current tree cover in the South West Goulburn is estimated at 24 %.

An important context for this project work is the effect of salt load reductions at the 'End of Valley' site identified by the MDBC (Murray Darling Basin Commission). The effects of the tree cover on salt load in the Goulburn River at Goulburn Weir and at Murchison are estimated in this project using the REALM model. REALM is the model currently used by the MDBC to evaluate the effects of land and river management on salt load carried to the Murray River by the major rivers in Victoria.

The linear relationships between (flow and tree cover) and (salt load and tree cover) are then used to estimate the change in salt load and stream flow for 8 REALM subcatchments within the South West Goulburn (these subcatchments do not include all of the South West Goulburn region as identified by the Goulburn Broken CMA). The inputs are the current tree cover and the estimated tree cover under each of the scenarios. The adjusted flow and salt load in the 8 subcatchments are then input to the REALM model and routed into the Goulburn River and downstream to Goulburn Weir and Murchison. The results are presented as a change in stream flow and salt load brought about by the proposed tree cover scenarios (Table i and Table ii).

- **Table i. The effects of four tree cover scenarios on modelled annual flow in the Goulburn River.**

	Tree Cover (%)	Reduction in Stream Flow into Goulburn Weir, GL/year. Also shown as % of current flow in ().	Reduction in Stream Flow at Murchison, GL/year. Also shown as % of current flow in ().
Current Land Use	24 %	*	*
Scenario 1	69 %	219 (8.1 %)	209 (20.5 %)
Scenario 2	57 %	166 (6.1 %)	159 (15.6 %)
Scenario 3	50 %	132 (4.9 %)	126 (12.4 %)
Scenario 4	33 %	49 (1.8 %)	47 (4.6 %)

- **Table ii. The effects of four tree cover scenarios on modelled annual salt load in the Goulburn River.**

	Tree Cover (%)	Reduction in Salt Load into Goulburn Weir, T/year. Also shown as % of current salt load in ().	Reduction in Salt Load at Murchison, T/year. Also shown as % of current salt load in ().
Current Land Use	24 %	*	*
Scenario 1	69 %	40,000 (23.3 %)	28,000 (32.8 %)
Scenario 2	57 %	29,000 (16.9 %)	21,000 (24.1 %)
Scenario 3	50 %	22,000 (13.0 %)	16,000 (18.8 %)
Scenario 4	33 %	9,000 (5.3 %)	7,000 (7.7 %)

Table i and ii represent the downstream effects of land use changes implemented in the South West Goulburn. The changes in stream flow and salt load into the Goulburn Weir Pool are directly relevant to downstream irrigators because irrigation water is diverted at this point. The changes in flow and salt load in the Goulburn River at Murchison (downstream of the Weir) are good indicators of the effects on the Murray River.

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Figure ii shows the percentage change in flow and salt load of the Goulburn River as it flows into Goulburn Weir. The percentage reductions in salt load are approximately 2.5 times larger than the percentage reductions in river flow. This occurs because the South West Goulburn is the source of approximately 44 % of the total salt load and only 12 % of the total flow into the Goulburn Weir (this is not shown in the Figures below but explains why salt load reductions are higher).

- **Figure ii. Change in flow and salt load into Goulburn Weir with increasing tree cover in the South West Goulburn. Note that the percentage reduction in salt load is approximately 2.5 times greater than the percentage reduction in stream flow.**

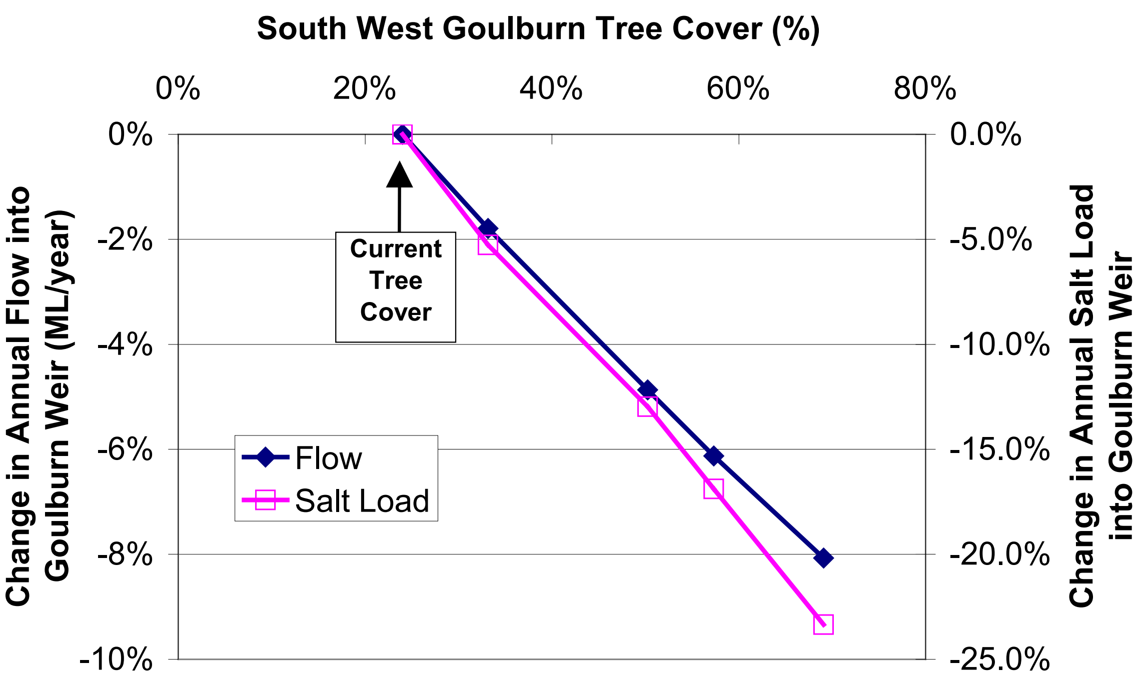
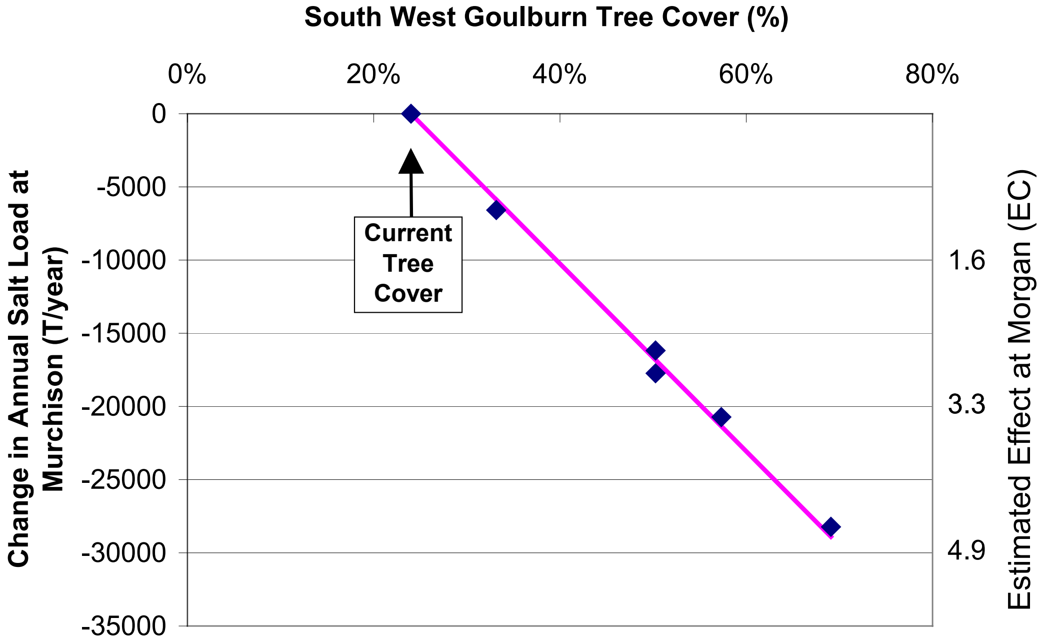


Figure iii below shows the change in salt load of the Goulburn River at Murchison as a function of tree cover in the South West Goulburn. The salt load at this point is carried to the Murray River. Note that the strongly linear response of salt load to tree cover (seen in Figures ii and iii) is partly an artefact of the approach used to estimate changes in stream flow and salinity. The linearity of the response to tree cover is best represented by the series of outputs from the MCS models of the case study areas (e.g. Figure i above).

▪ **Figure iii. Change in Salt Load at Murchison vs tree cover in the South West Goulburn. An estimate of the effect on EC at Morgan is given on the axis on the right.**



Conclusion

This project has interrogated the MCS model to improve understanding of how it represents different aspects of catchment salt and water balance. Some improvements in the models of the case study areas are made and then, at the scale of the South West Goulburn, the results are used to estimate the effects of trees on stream flow and salt load.

Key Conclusions for the Methodology:

- Proposals for land use change in the South West Goulburn can be examined using the MCS and REALM models. These models allow the salt load reduction to be estimated for the Goulburn River at the end-of-valley.
- The conclusions reached are considered to be robust and are not strongly dependent on any particular input parameter to the MCS model.

Key Conclusions for Catchment Management:

- An increase in tree cover is effective in reducing the salt load exported from the South West Goulburn. (Other deep rooted vegetation with similar water use characteristics to the modelled trees would also be as effective.)
- The increased water use by trees (compared to pasture) is effective in reducing salt load regardless of where the trees are located. **It is likely to be more effective increasing percentage tree cover than siting a lower tree cover in the best locations.**
- Optimising the spatial distribution of trees can provide small additional gains in salt load reduction for a given area of trees. These additional gains are secondary to the primary advantage gained from percentage tree cover. (For example, using the results presented in Figure i, an increase in tree cover from 9.7 % to 45 % causes a reduction in salt load of 39 % ± 6 %, where 6 % represents an additional salt load reduction possible if tree locations are optimised.)
- Small blocks of trees in areas with high watertables are unlikely to be effective in long term salt load reduction. However, local groundwater salinity and groundwater drainage conditions will influence this result (e.g. use of low salinity groundwater by trees may be effective in some settings).
- Significant reductions in Murray River salinity could be achieved by large scale tree planting. The current area of trees in the South West Goulburn (approximately 24 %) would need to be approximately doubled to achieve a salinity reduction at Morgan of 3 EC. In addition, tree planting also reduces the salinity of irrigation water diverted from Goulburn Weir to the Shepparton East Main Channel and the Waranga West Main Channel.
- Specifically, a 50 % tree cover in the South West Goulburn would reduce the salt load into Goulburn Weir by 13.0 % and this would be associated with a 4.9 % reduction in flow (see Table i and Table ii). These reductions quantify the effect of increased cover on downstream irrigators. The reductions would be 12.4 % and 18.8 % for flow and salt load in the Goulburn River at Murchison (this quantifies the effects on the Murray River).
- Application of the model indicates that the development of small-scale groundwater pumping schemes should be further evaluated as an effective approach to reducing salt load. The salt load benefit of establishing an area of irrigated grapes is found to be up to twice as effective in reducing salt load as planting an equally-sized area to trees.
- A preliminary economic analysis using typical incentives available through the Goulburn Broken CMAs program revealed that, where suitable groundwater reserves could be located, groundwater based irrigation enterprises would provide a more cost effective return on public investment for salt load reduction than revegetation.

- The tree cover scenarios developed in this report provide input to more comprehensive evaluations of land management options that would also consider economic and social influences on land managers. The scenarios are best considered at the scale of the South West Goulburn, however the rules/principles used to locate trees are also useful at the paddock scale. Thus, paddocks where the watertable lies at a depth less than 5 m are unlikely to be effective in long-term salt load reduction.

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1. Introduction

Sinclair Knight Merz have been engaged by the Goulburn Broken Catchment Management Authority to undertake a second part of the South West Goulburn project. The first part of the project was a collaboration between the Dept. of Primary Industries and Sinclair Knight Merz with DPI taking the lead role. The final report for Part 1 is as:

The South West Goulburn Salinity Study,
CLPR Research Report No. 28, June 2003.

> by Xiang Cheng, Mark Reid, Paul Rampant, Geoff Savage, Karen Lees, Carl Daamen, Greg Hoxley and Adrian Costar.

This second part of the South West Goulburn project follows on directly from the first part and this report is best read in conjunction with the report from Part 1. Part 2 is another collaborative project between Sinclair Knight Merz and DPI with Sinclair Knight Merz now taking the lead role.

The objectives for work in Part 2 of the South West Goulburn (SWG) project have been identified from a series of draft proposals and from discussions held at the Goulburn Broken CMA in Yea on the 6th November, 2003. The final proposal was dated 8th December 2004. The objectives and scope of work are presented in the following section.

2. Project Overview

2.1 Project Objectives and Scope of Work

This project follows on directly from Part 1 of the project and, indeed, the Part 1 report provides the background necessary to fully understand this report.

In Part 1, the water and salt balance of two case study areas (Gardiner Creek, 51 km^2, and Hamilton/Dry Creeks, 40 km^2) was modelled using an approach developed by Sinclair Knight Merz. This approach is now called the Management of Catchment Salinisation or MCS model. It has two primary component models: (1) a soil profile model, SoilFlux that uses a daily timestep, and (2) a groundwater model that models average annual fluxes and is used in steady state mode for this project.

In Part 2 of the project, specific questions are answered regarding the MCS model and some model sensitivity testing is undertaken. The primary objective of Part 2 is to work at the scale of the whole South West Goulburn (3000 km^2) and to identify areas that would result in an effective reduction of salt load export through planting native vegetation/trees. The understanding gained in Part 1 of the effects of trees on catchment water and salt balance is a major input to reaching this objective.

Specifically, the project objectives are:

1) **To evaluate and explain components of the modelling approach in order to assist with communication of the results to the community and to provide information to support the completion of Objective 3.**
2) **To use targeted sensitivity testing of the modelling approach to improve understanding of the outputs and of the limitations/strengths of the approach. The outputs of the testing will be used directly in achieving Objective 1 and Objective 3.**

The primary objective of this project:

3) **Develop rules to identify locations best suited to growing trees that would provide long term control of land and stream salinisation across the SWG (a spatial distribution of these locations will be mapped).**

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- **Figure 2-1 Flow diagram for tasks in the project Tree Cover for Salinity Management in the South West Goulburn. The dotted line frames the essential components of the project.**

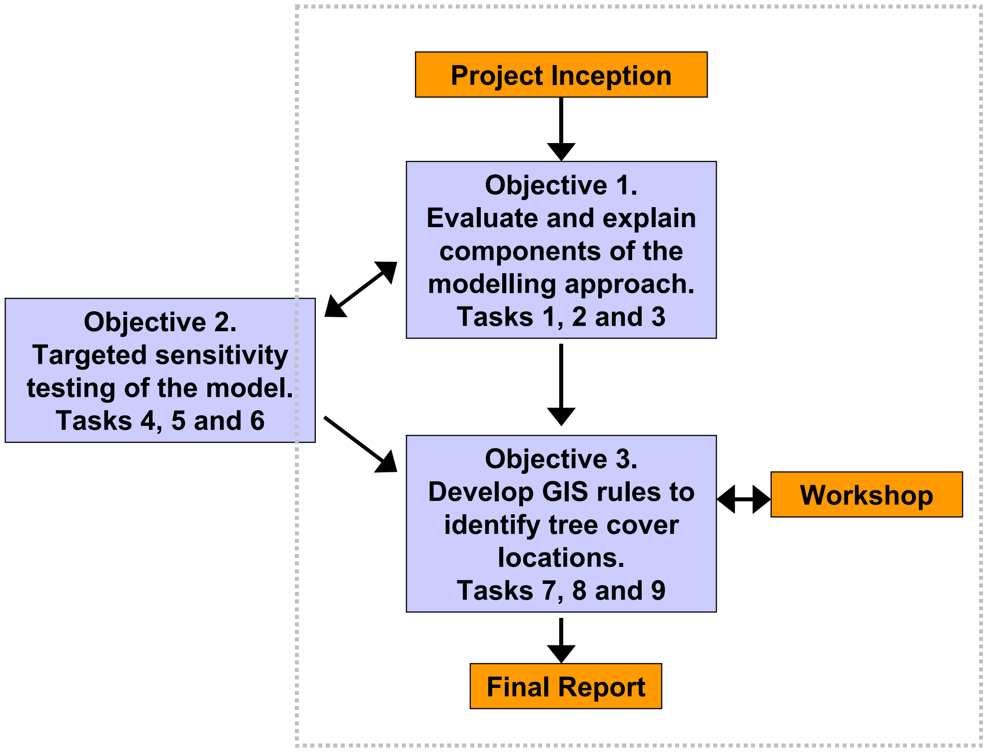


Figure 2-1 provides an overview of how the objectives and tasks fit together.

Two meetings (on 12th February 2004 and 2nd April 2004) were held at Sinclair Knight Merz in Melbourne to develop the approach to identify effective locations for native vegetation/tree cover. The project workshop was held on 11th May at Trawool and included two members of the Upper Goulburn Implementation Committee.

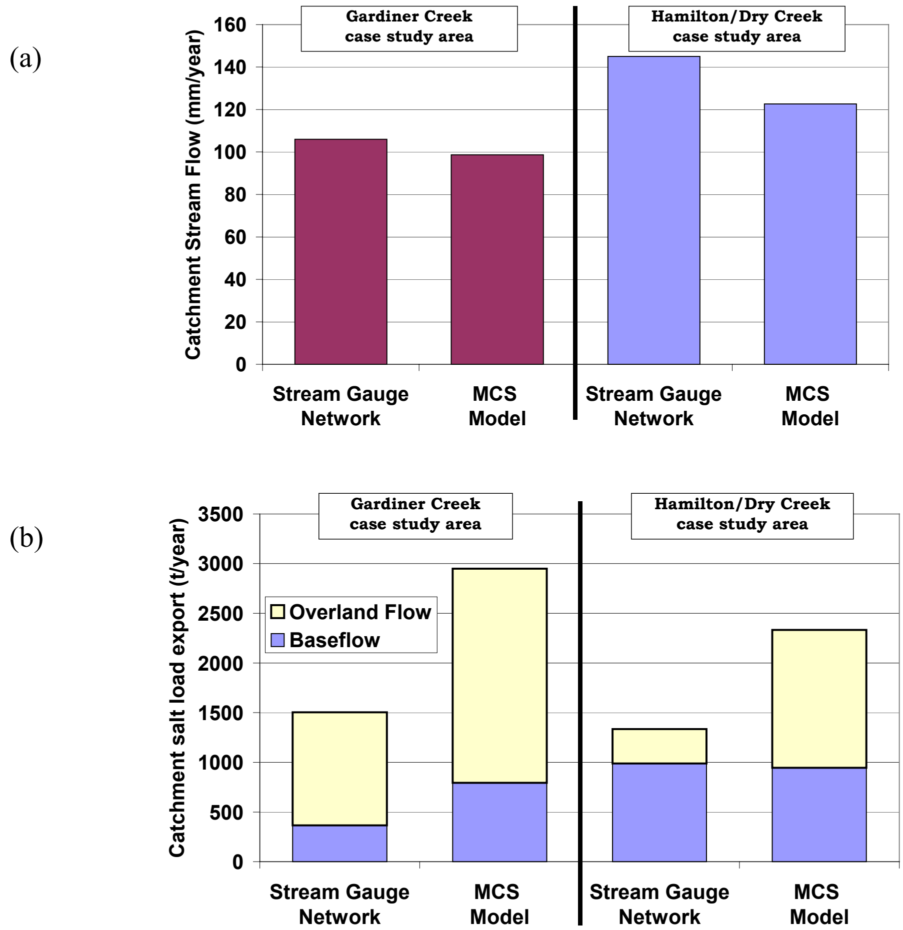
An additional task was added during the course of the project. This task was to model the effect of small-scale groundwater pumping schemes for irrigated crops (e.g. grapes or olives) on catchment salt load export and to compare it with planting of native vegetation/trees. This task is also reported below.

3. Description of the Modelling Approach

3.1 Task 1: Comparison of Salt Load Estimates

The South West Goulburn Part 1 report presented two independent approaches to estimating average annual runoff and salt load in the case study areas. The first approach used data from stream gauges in the surrounding catchments to estimate the annual fluxes from Gardiner Creek and Hamilton/Dry Creek case study areas. The second approach used the Management of Catchment Salinisation (MCS) model of hydrological processes contributing to runoff and salt load. In both case study areas the agreement between the approaches was good for average annual runoff, and not as good for salt load (Figure 3-1).

▪ **Figure 3-1 Average annual runoff (a) and salt load export (b) from the case study areas (as presented in Part 1 of the project).**



A closer agreement was sought between salt loads estimated from the stream gauge network and the MCS model. However, the agreement between the two approaches is not thought to be unreasonable because stream salt load is so difficult to estimate. The factors that may be contributing to the difference between estimates are discussed below.

- **Catchment Characterisation**. The conceptual model of the hydrogeology is necessarily simple and it is intended to describe the whole-of-catchment response. However, salt export is likely to be affected by details of the hydrogeology e.g. changes in aquifer parameters near to drainage lines. Furthermore, assuming the conceptualisation is acceptable, the values of soil and aquifer properties that have been used may not be optimal due to the limited available input data.
- **Conceptualisation of processes.** The MCS model characterises (a) the fluxes in soil profiles as a function of depth to watertable and (b) the lateral movement of groundwater in response to recharge from soil profiles. There are a number of additional processes and refinements of the current descriptions that may be important to an estimate of salt load. These include: lateral movement of groundwater at some boundaries between soil layers (hillslope processes); seasonal fluctuation in depth to watertable and modelling of the surface runoff process on a minute by minute basis, rather than the daily basis currently used. These refinements are beyond the scope of this study.
- **Limitations of the data set for stream salinity.** A flux estimate from a continuously recording gauge might usually be considered to be the data against which a model is compared or calibrated. In the case of salt load, continuous measurements of stream salinity have only been routinely recorded since 1990 near to the case study areas and data sets from only 1990 to 2000 were used in the analysis. While corrections were made to adjust for climatic conditions the short measurement period may not have characterised a long term average catchment salt load. In addition, care was taken to fill in data gaps as accurately as possible although these remain as another source of error. Therefore, the short length of record and the ephemeral nature of streams in the study area reduce the reliability of the salt load estimate from stream gauges.
- **Groundwater salinity and salt stores.** Groundwater salinities have been recorded in groundwater discharge zones for longer periods within the case study areas. In addition, groundwater salinity is now being recorded in the new bores outside these discharge zones. However, there is only a limited characterisation of groundwater salinity across the case study areas and limited identification of areas of high soil salinity. Further information on soil and groundwater salinity would assist in the modelling of catchment salt load export.

This project has considered the sensitivity of the MCS model outputs to some input parameters and this has allowed the difference between the two salt load estimates to be reduced (see Section 4.7).

The discussion above indicates why the agreement between the salt load estimates may not be as good as the agreement between annual stream flow estimates. However, a very important question that remains is: ***What are the implications for confidence in the modelled change in salt load due to afforestation if the MCS model salt load is significantly larger than that estimated from stream gauge data?*** Put differently: ***Would the modelled change in salt load caused by increased tree cover be different if the MCS model was re-calibrated to give a lower salt load under current land use (***Figure 3-1***)?***

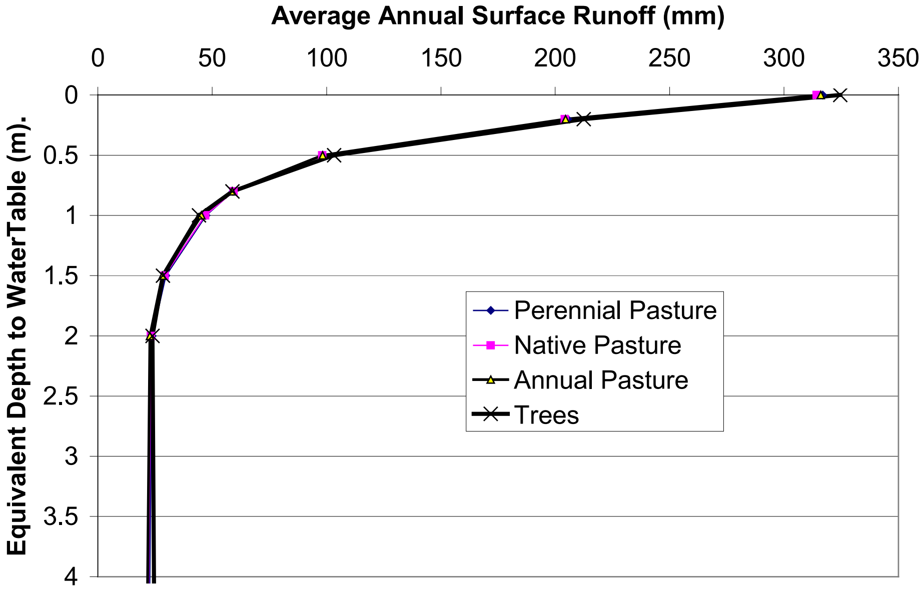
Our conclusion is: **The percentage change in salt load caused by increased tree cover is robust and is not likely to be greatly affected by changes to the MCS model.** If re-calibration of the model does not change the representation of hydrological processes the percentage change in salt load is expected to be very similar. The sensitivity testing and improved representation of the case study areas support this conclusion.

3.2 Task 2: Representation of Surface Runoff

The South West Goulburn Part 1 report indicated that runoff did not change greatly with land use in the SoilFlux model (Figure 3-2). Runoff in SoilFlux is most strongly influenced by the underlying depth to watertable. However, it does NOT follow that planting significant areas to trees can only affect the modelled stream flow through changes to stream baseflow.

When trees replace pasture in a catchment groundwater recharge is reduced. This has two primary effects: (1) stream baseflow is reduced (the input and therefore the output to the groundwater system is reduced), and (2) the catchment area with shallow watertables is reduced. Figure 3-2 shows a strong response of surface runoff to depth to watertable demonstrating that the MCS model accounts for the effects of planting trees on both baseflow and surface runoff at the catchment scale.

Figure 3-2 SoilFlux model output: runoff from the land surface as a function of underlying groundwater potential. Data are shown for four vegetation types growing on soil profile B (described in Appendix K of the Part 1 report).



Runoff from the land surface is known to be affected by surface roughness (i.e. capacity to store a volume of water in puddles above the land surface), average surface slope, formation of a soil crust, and factors like the presence of leaf litter at the soil surface. Therefore the nature of the vegetation present is likely to have an effect on runoff. However, it would be inappropriate to differentiate between trees and pasture in terms of land surface condition without an objective basis for this differentiation. A conservative approach is adopted and no distinction is made between vegetation types in terms of land surface condition. (Differences in surface runoff can still occur between vegetation types as a result of difference in vegetation water use and thus soil water content.)

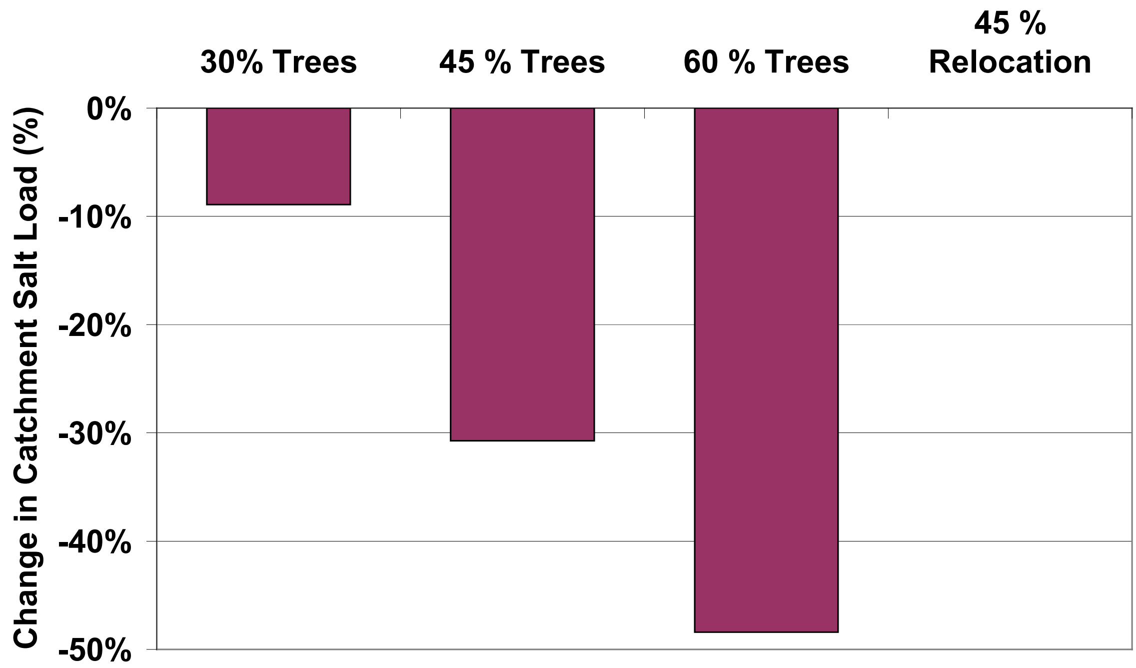
It is thought that the effect of vegetation on the representation of surface runoff represents a level of greater model complexity than the current approach. Characterisation of runoff effects by vegetation type would probably require input of details of rainfall intensity perhaps on a minute by minute basis, rather than the daily basis currently used.

3.3 Task 3: Differences in the Response to Afforestation

3.3.1 Change in salt load for percentage catchment tree cover

The tree planting was not as effective in reducing salt load in the Hamilton/Dry case study area as it was in Gardiner. Figure 3-3 and Figure 3-4 present the data from Part 1 of the project to demonstrate the effect of tree planting on salt load. Also, when tree planting was concentrated along stream lines there was a much less effective reduction in salt load in both catchments (see column labelled '45% relocation' in Figure 3-3 and Figure 3-4).

▪ **Figure 3-3 Gardiner Creek: reduction in salt load of land use change scenarios relative to salt load under current land uses (results from Part 1 of the project). Note that the '45 % Relocation' scenario did not change the modelled salt load.**



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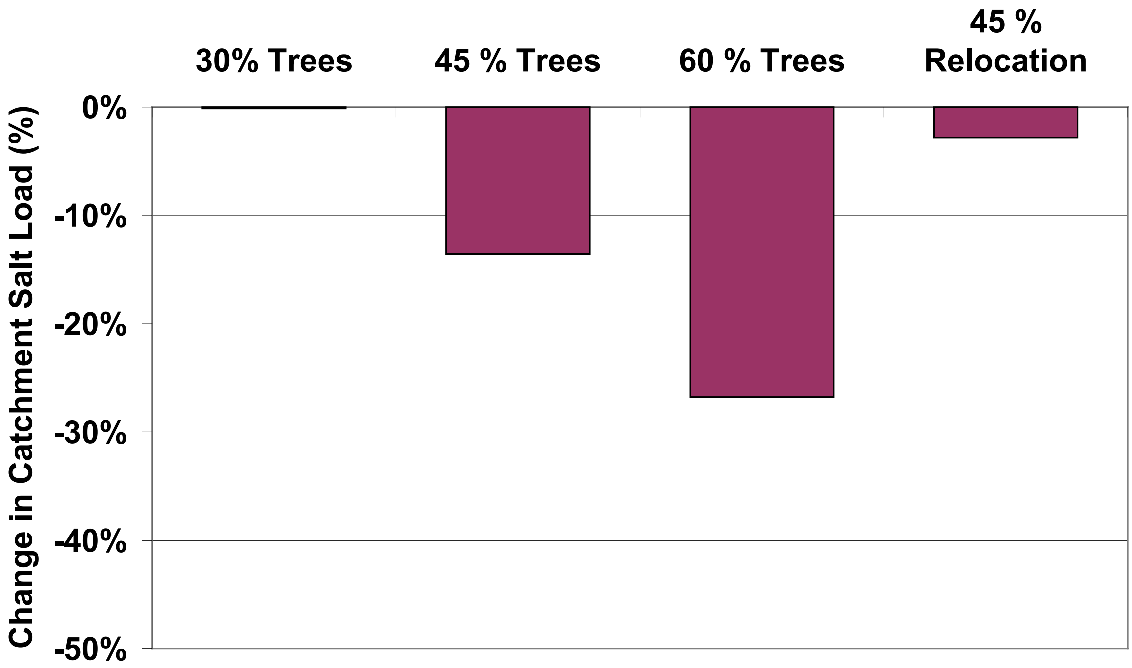
- **Figure 3-4 Hamilton/Dry Creek: reduction in salt load of land use change scenarios relative to salt load under current land uses (results from Part 1 of the project).**



The difference in salt load reduction between the case study areas has occurred because the watertable is shallower beneath trees in Hamilton/Dry than it is in Gardiner Creek. Figure 3-5 and Figure 3-6 show how much of the tree area has an underlying watertable greater than 10 m. Clearly Gardiner Creek has a greater proportion of the tree area overlying watertables at depths greater than 10 m. In addition, trees on areas with shallow watertables can result in a small increase in salt load because salt is transported to the soil surface.

Figure 3-7 shows the distribution of land surface elevations within the two case study areas. Gardiner Creek has a wider range of elevations in the 70 % of the catchment lying around the median value. The spread of elevations is likely to contribute to a greater catchment area with deeper watertables.

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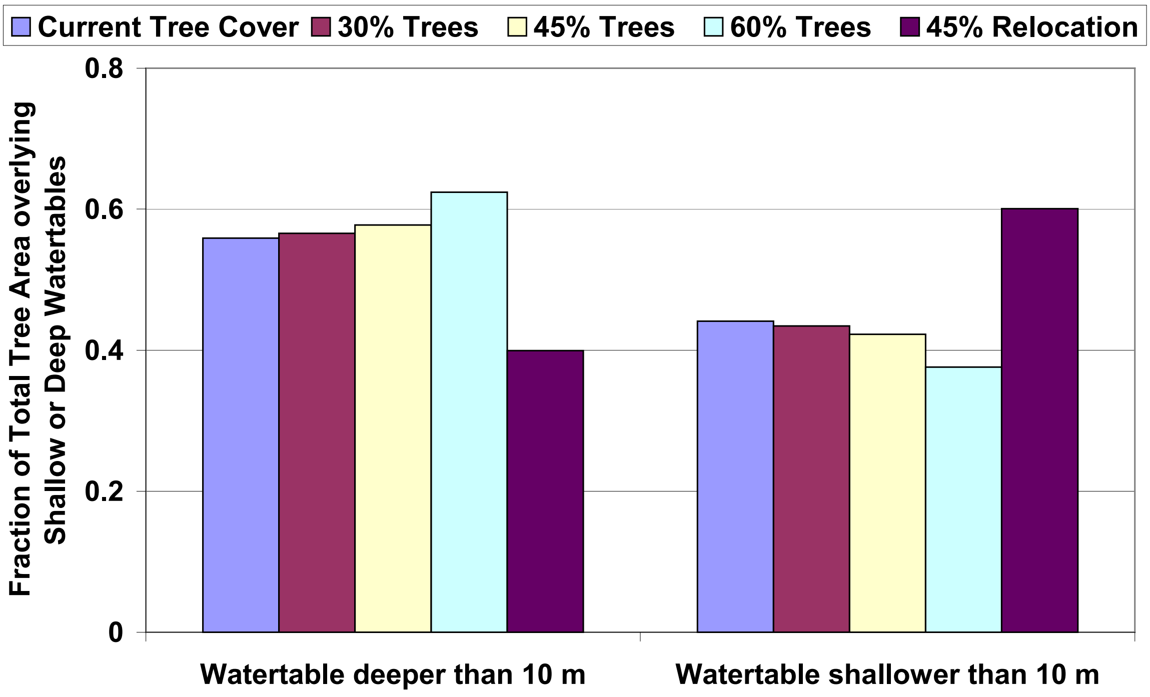
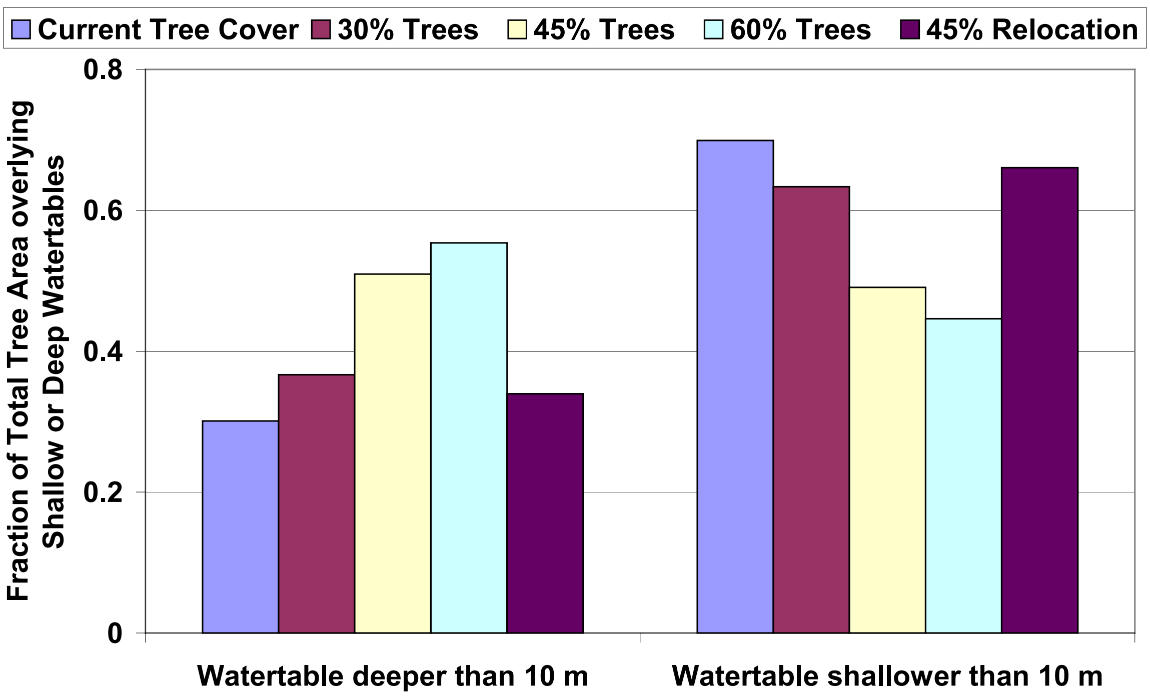
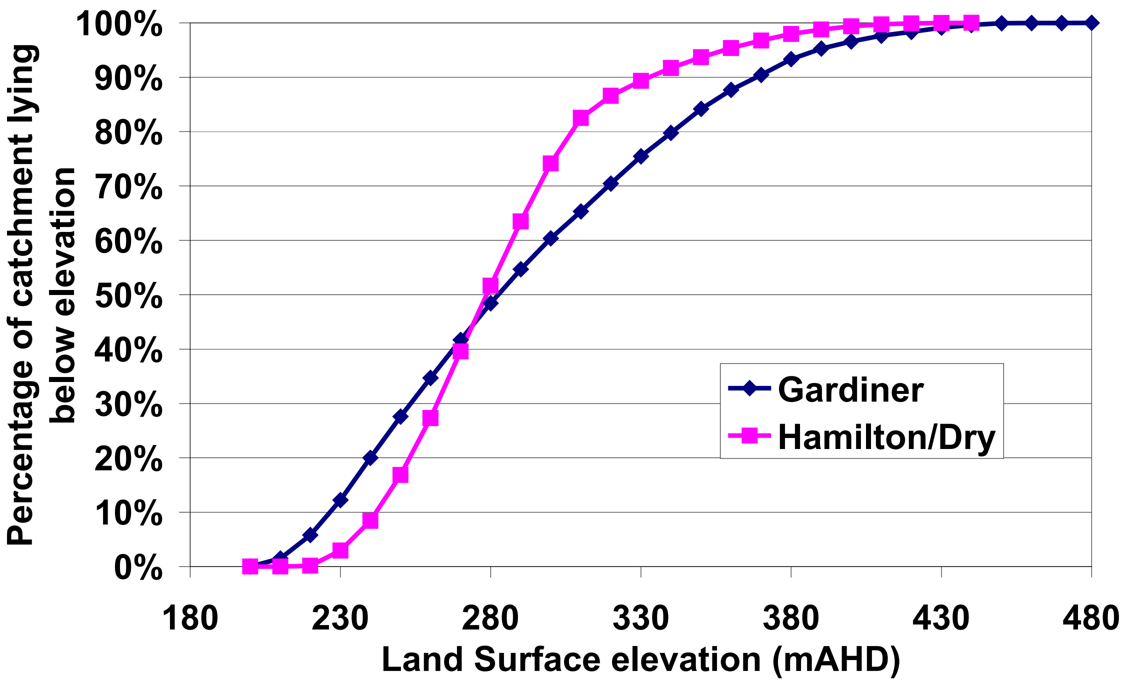
- **Figure 3-5 Gardiner: depth of watertable underlying trees for different tree cover scenarios (scenarios taken from Part 1 of the project).**



- **Figure 3-6 Hamilton/Dry: depth of watertable underlying trees for different tree cover scenarios (scenarios taken from Part 1 of the project).**



▪ **Figure 3-7 The distribution of land surface elevations in the case study areas.**



3.3.2 Response Time to Land Use Change

The response time to land use change is longer in Gardiner Creek in part because of the wider range in topography (Figure 3-7). There are significant areas in Gardiner Creek where the watertable is more than 40 m below the land surface. In these areas the transmissivity of the aquifer system is low (transmissivity is a function of the depth of saturation in a layer and the hydraulic conductivity). Areas with low transmissivity require long time periods for the watertable to respond to a change in recharge conditions and approach a new equilibrium position.

4. Sensitivity Testing of the Modelling Approach

4.1 Task 4a: Parameters input to the salt washoff module in the SoilFlux model

The surface runoff component of salt load appeared to be too large in the results presented in the Stage 1 report (see also Figure 3-1). This task investigates the effects of a change in the parameters of salt wash off on the mobilisation of salt in the near-surface.

The MCS modelling approach considers two processes of solute transport to streams and therefore out of catchments. The first process is runoff or overland flow that carries salts from the soil surface or near-surface to stream beds. The second process is the groundwater discharge (or baseflow) to streams. In this task we investigate the sensitivity of model outputs (in particular the salt load) to parameters used in the description of the first process.

The salt carried in runoff at the land surface is calculated using the following parameters:

- z_{salt} (m), the soil depth at the surface from which salt is available to be carried in runoff;
- f_{salt} , the fraction of the total mass of salt held between the surface and depth z_{salt} that is to be carried by runoff;
- c_{max} (mg/L), the maximum salinity concentration of runoff (this parameter is required to reduce the salt load carried in runoff when the runoff volume is small, e.g. $\ll$ 1 mm).

The values used in the first part of the South West Goulburn project for z_{salt}, f_{salt} and c_{max} were 5 mm, 0.5 and 10,000 mg/L respectively. These values had been estimated in an investigation at another site.

In this Task we investigate the sensitivity of model outputs to z_{salt} and f_{salt} . Results are presented below for values of z_{salt} equal to: 2.5 mm, 5 mm and 10 mm and values of f_{salt} equal to: 0.2, 0.5 and 0.8. The sensitivity to the parameter c_{max} is not evaluated here[1].

The SoilFlux model was run for a 50 year period and annual averages calculated for the last 20 years of the climate record. Figure 4-1 shows the solute concentration in runoff from a soil profile for the land use 'trees' in the Hamilton-Dry case study area. The results shown in Figure 4-1 were found to be reasonably representative of all land uses and both case study areas. This is the case

[1] This parameter is primarily used to limit the concentration of runoff for rainfall events where very small volumes of water are running off (e.g. less than 1 mm depth). In these cases the mass of salt that is available for runoff can be large and if the whole salt mass was to be carried off by a small volume of water the concentration of runoff would need to be unrealistically high. The parameter c_{max} is not expected to be significant to salt load estimates except in areas where the underlying watertable is at or near to the soil surface.

because the shallow depth to watertable has a much greater influence on the salt and water balance than the vegetation type, soil type or annual rainfall in these case study areas.

Note that the 'underlying depth to watertable' indicated in the figure refers to the boundary condition at the base of the simulated soil profile. A water potential equivalent to the depth to watertable is held constant at the base of the profile, the actual depth of unsaturated soil that occurs within the profile is variable and is strongly influenced by the prevailing climatic conditions.

- **Figure 4-1 Flow weighted concentration of runoff (mg/L) for three underlying depths to watertable. The effect of a variable f_{salt} is shown on the left of the figure and the effect of a variable z_{salt} is shown on the right.**

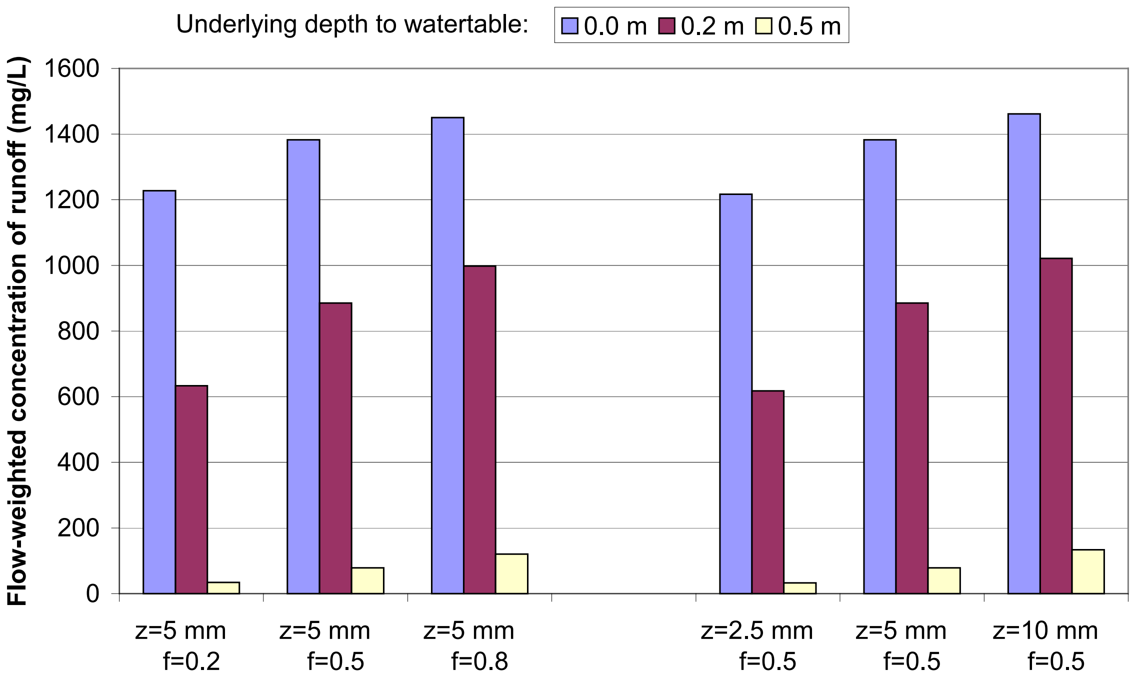
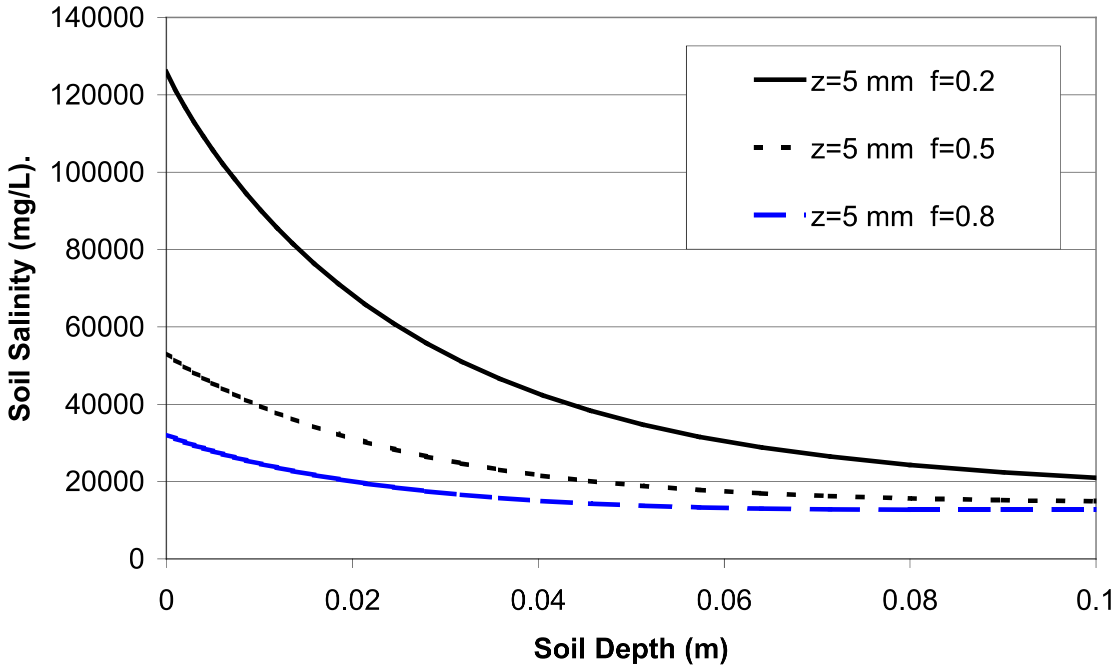


Figure 4-1 indicates that the solute concentration in runoff is most strongly affected by the underlying depth to watertable, as expected. The salinity of the underlying watertable is modelled as 1000 mg/L, using the restricted available data from the groundwater bores. Model sensitivity to groundwater salinity is considered later in this report.

The effects of the values of z_{salt} and f_{salt} are quite similar (Figure 4-1) – these two parameters control the mass of salt that is available to be washed off. The percentage effects of the salt wash-off parameters z_{salt} and f_{salt} increase as the depth to watertable increases [thus the percentage difference between columns on Figure 4-1 at (z_{salt} =5 mm , f_{salt} =0.2) and (z_{salt} =5 mm , f_{salt} =0.5) is much greater for an underlying watertable at 0.5 m than it is for a underlying watertable at 0.0 m] .

The distribution of salt within the soil profile will also be affected by the z_{salt} and f_{salt} parameters. Figure 4-2 shows the soil salinity near the land surface at the end of a 50 year period for three values of f_{salt} and an underlying depth to watertable of 0.2 m. At the end of these long periods it is expected that the soil profile is approaching an equilibrium condition for soil salinity and thus the net salt inflow is approximately equal to the net salt outflow. For example, if the f_{salt} parameter is halved the soil salinity needs to be twice as high to maintain the same salt load in runoff from a profile and this is shown in the figure.

- **Figure 4-2 Soil salinity from 0.0 m to 0.1 m at the end of a 50 year simulation run with an underlying depth to watertable of 0.2 m. Salinity profiles are shown for three different sets of parameters used in the salt washoff subroutine.**



The salt load carried in runoff is only significant for a soil profile in a condition of net groundwater discharge. A significant discharge condition occurs when the watertable is close to the soil surface (< 0.5 m, but depends on the type of vegetation present). However, when the depth to watertable is 0.5 m or greater the salt load in runoff is actually less than the salt inflow in rainfall. The salinity of rainfall is modelled at 10 mg/L delivering an average of 6.5 (g salt)/m^2/year. The salt load carried in runoff is 3.4 (g salt)/m^2/year for parameters (z_{salt} =5 mm , f_{salt} =0.5) and a depth to watertable of 0.5 m. Therefore, the distribution of soil salinity with depth is not as sensitive to the salt washoff parameters when the underlying watertable is at a depth of 0.5 m or greater. This is in contrast with the results shown in Figure 4-2.

4.2 Task 4b: SoilFlux Sensitivity to the Representation of Trees

In this task we consider how the representation of trees in the model affects the soil water balance. The primary land use change investigated in this project is a change in land use to trees and therefore the model representation of trees is fundamental to the predicted changes in catchment salt and water balance.

Appendix A is a brief literature review of studies that provide context to the description of trees in the SoilFlux model. Tree root systems are often deep (>= 10 m) in climates similar to the South West Goulburn. Unfortunately, the few local studies of tree water use do not provide enough information to input directly to the MCS models. Two of the main concerns are: (1) the depth of tree roots in parts of the South West Goulburn where the soil is shallow; (2) the establishment of a 'full' tree canopy that maximises possible water use. Below we evaluate the sensitivity of the soil water balance to these two inputs for a land use of trees.

Specifically the SoilFlux model runs were as follows:

- **Standard** – assumes a canopy leaf area index between 2 and 3 and a root depth of 8 m (as used in all model runs for this project)
- **Half Canopy** – assumes a leaf area index of about 1 with a root depth of 8 m
- **Roots to 4 m** – assumes a leaf area index between 2 and 3 and a root depth of 4 m
- **Half Canopy +Roots to 4 m** – assumes a leaf area index between 2 and 3 and a root depth of 8 m.

The Soil Flux model was run for a 50 year climate period and two soil types. The results from the two soils were similar, therefore the results are only presented below for one soil profile. Figure 4-3 shows the average annual groundwater discharge or recharge for a series of underlying groundwater pressures. This information is used to estimate the inputs to the groundwater model for trees – in particular the maximum soil depth from which tree roots can extract water. As expected this is affected by the modelled depth of roots but the canopy development (or potential rate of root water uptake) is also important. Root water uptake effectively extends to a depth of about 5.5 m in the 'Half Canopy + Roots to 4 m' case and 10 m in the 'standard' case.

Root water uptake is significantly reduced by salt accumulation in the root zone when the underlying watertable is at 2 m or higher. Figure 4-4 shows the salt accumulation in the soil between 0.0 m and 0.3 m, salt accumulation over this depth range is much slower when the tree canopy is less dense (compare the 'half canopy' runs with the other two).

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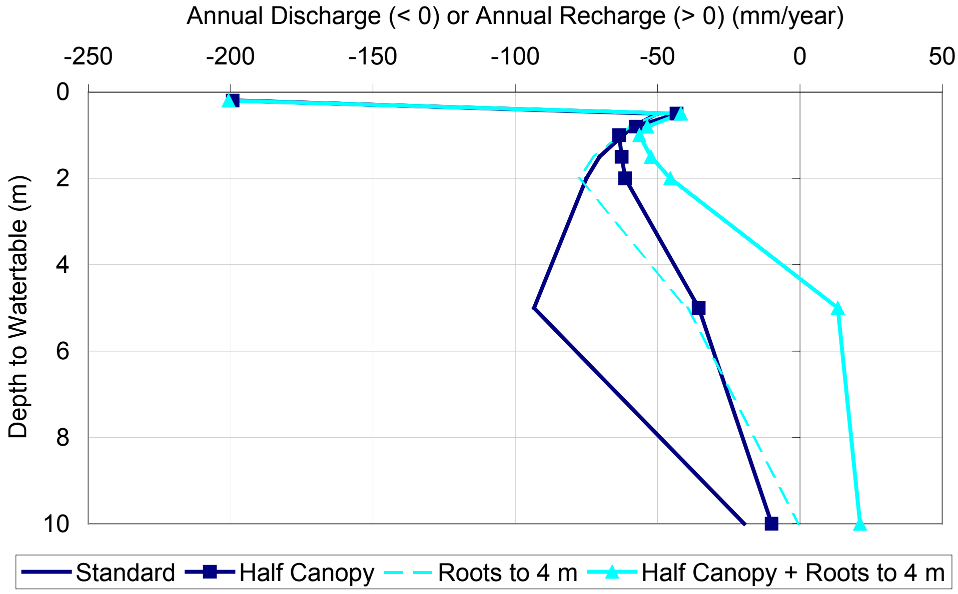
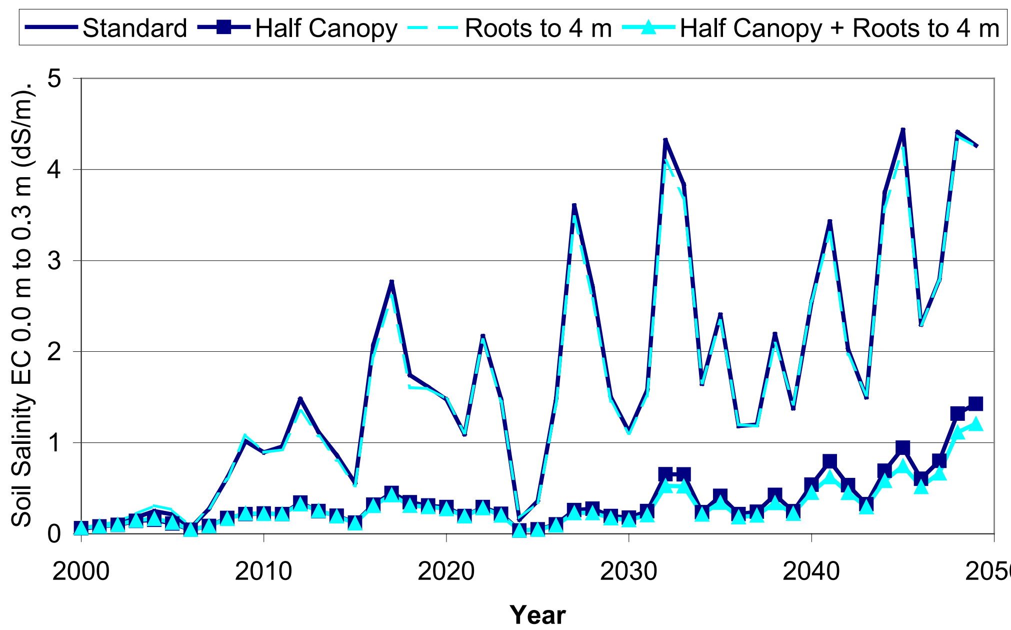
▪ Figure 4-3 Annual groundwater discharge or recharge vs underlying depth to watertable for trees. Points plotted are averages calculated over the last 20 years of a 50 year period for one soil type in the Gardiner Creek case study area.



▪ Figure 4-4 Average annual soil salinity (0 m to 0.3 m) over a 50 year period for the four model representations of trees. The underlying groundwater pressure is equivalent to a depth to watertable of 0.8 m.



The effect of salt accumulation in the root zone acts to reduce the differences between the four different model representations of trees. In the 20 years after planting, stands of trees/shrubs that are using more water than others (because they have a denser canopy and a deeper root zone) are likely to be drawing on groundwater as an additional water source to rainfall. The use of groundwater comes at the cost of salt accumulation in the tree root zone that then reduces the ability of the tree stand to continue using more water than other trees nearby.

Therefore our model results of long term catchment salt and water balance are not highly sensitive to the model representation of trees. Further sensitivity testing could also include the groundwater model. Further experimental work investigating the soil water balance under trees in the local area would provide information that would improve the constraints of a sensitivity test like this one (e.g. what is a realistic range of tree root depths).

4.3 Task 5a: New Representation of Areas of High Recharge in the Groundwater Models

The final hydrogeological interpretation in Part 1 of the South West Goulburn project identified high priority areas for recharge control (Cheng et al., 2003, Figures 11 and 12). These features were not represented in the groundwater models in Part 1 because the interpretation of recharge areas was only completed at the end of the project and there was not time or resources to edit the model and re-run the scenarios. The interpretation requires an increase in the aquifer hydraulic conductivity around the Moormbool fault in Gardiner Creek and along the eastern side of Dry Creek in Hamilton/Dry Creek case study area. In Task 5a, the new aquifer properties were assigned to the identified areas to examine their effect on the model results.

Aquifer properties for the priority areas were provided by PIR Vic (Frankston and Benalla). Table 4.1 summaries the parameter values used within the priority areas of high recharge in Gardiner Creek. Note that the new interpretation of the Moormbool fault replaced the representation used by Cheng et al. (2003) in Part 1 of the project.

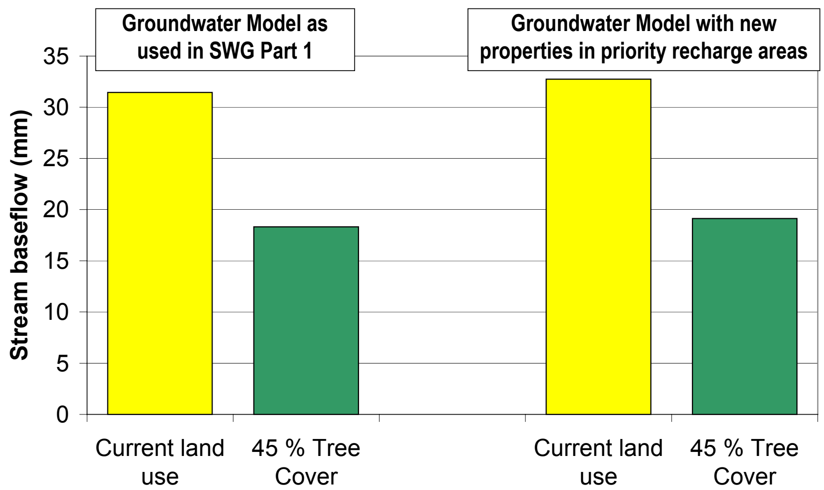
- **Table 4.1 Gardiner Creek case study area: comparison of aquifer parameters used in the groundwater model within the priority areas and generally elsewhere in the model.**

	New Properties in Priority Areas of High Recharge	General values of properties within the model
Gardiner Creek Layer 1		
Lateral hydraulic conductivity K_x and K_y (m/day)	0.3	0.3
Vertical hydraulic conductivity K_z (m/day)	0.2	0.03
Specific Yield (-)	0.03	0.03
Gardiner Creek Layer 2		
Lateral hydraulic conductivity K_x and K_y (m/day)	0.2	0.03

Vertical hydraulic conductivity K_z (m/day)	0.2	0.03
Specific Yield (-)	0.01	0.01
Gardiner Creek Layer 3		
Lateral hydraulic conductivity K_x and K_y (m/day)	0.001	0.0001
Vertical hydraulic conductivity K_z (m/day)	0.001	0.0001
Specific Yield (-)	0.0001	0.0001

Figure 4-5 presents a comparison of a component of the model water balance before and after implementation of the new aquifer properties in the priority areas. The new representation of the Moormbool fault made little difference to the analysis of the effects of afforestation. Indeed, the effects to the salt and water balance in the case study area and the modelled watertable conditions were not highly significant. It is likely that the results are so similar because the new representation of the Moormbool fault replaced another (narrower) representation that had similar effects on the model water balance.

- **Figure 4-5 Gardiner Creek case study area: comparison of the stream baseflow component before and after adoption of the new representation of aquifer properties around the Moormbool fault.**



In the Hamilton/Dry case study area the priority area of high recharge was not previously represented by an area with different aquifer properties. Table 4.2 compares aquifer properties used in the model before and after implementation of the description provided by PIR Vic.

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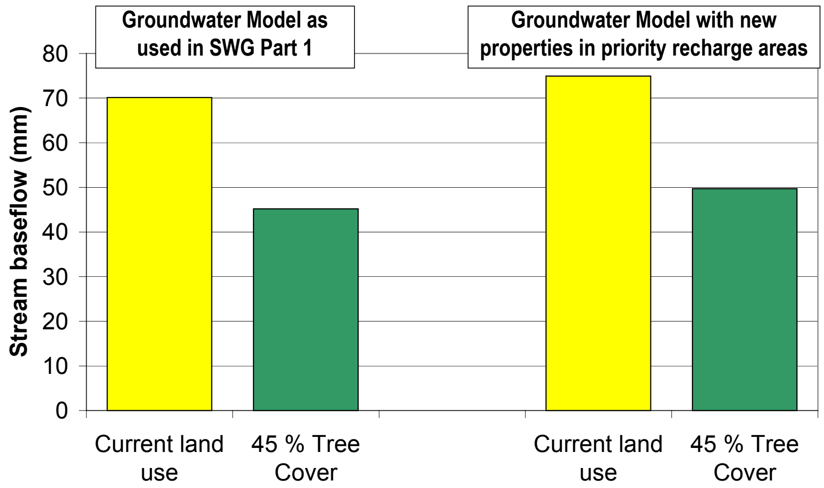
Table 4.2 Hamilton/Dry Creek case study area: comparison of aquifer parameters used in the groundwater model before and after implement of the new description of the priority area.

	New Properties in Priority Areas of High Recharge	Old Properties in Priority Areas of High Recharge
Hamilton/Dry Creek Layer 1		
Lateral hydraulic conductivity K_x and K_y (m/day)	0.8	0.2
Vertical hydraulic conductivity K_z (m/day)	0.5	0.02
Specific Yield (-)	0.03	0.03
Hamilton/Dry Creek Layer 2		
Lateral hydraulic conductivity K_x and K_y (m/day)	0.1	0.03
Vertical hydraulic conductivity K_z (m/day)	0.1	0.03
Specific Yield (-)	0.02	0.001
Hamilton/Dry Creek Layer 3		
Lateral hydraulic conductivity K_x and K_y (m/day)	0.001	0.0001
Vertical hydraulic conductivity K_z (m/day)	0.001	0.0001
Specific Yield (-)	0.0001	0.0001

Figure 4-6 shows the effects of the new representation of the high recharge priority area within the Hamilton/Dry case study area. Figure 4-6 indicates little change in the water balance at the scale of the case study area. However, the priority area was not previously differentiated from the rest of the model in this way and furthermore it lies along a model boundary. For these two reasons the groundwater system in the valley of Dry Creek is affected by the new representation, in particular, the watertables are lower in this area. Further investigation would be required to further fine-tune the model in the priority area.

■ **Figure 4-6 Hamilton/Dry Creek study area: comparison of the stream baseflow component before and after adoption of the new representation of aquifer properties on the eastern side of Dry Creek.**



The development of the groundwater models to represent the priority areas of high recharge is maintained in further model developments described below.

4.4 Tasks 5b and 5c: Representation of the Depth of Stream Beds and the Land Areas Adjacent to Streams in the Groundwater models

Streams were represented in the groundwater models as MODFLOW drains (Cheng et al., 2001). The two inputs required for a drain are the depth below the land surface and the conductance. The groundwater model cell dimensions are 50 m by 50 m therefore a stream bed will not be represented as a dip in the land surface because it is typically less than 10 m wide and because surveyed elevation points do not often lie in stream beds. Therefore the drain depth will represent the depth of incision of a stream bed below the land surface. The conductance represents the ease with which groundwater can move to a stream bed/drain within a model cell containing a drain. It will be affected by aquifer characteristics, the length of stream bed within the cell and the hydraulic conductivity of the material lining the stream bed (e.g. silts and clays).

Some additional small tributary streams within the model areas were added to the groundwater models used in the project for Part 1. This improved the representation of the depth to watertable along the tributary stream lines. Representation of small tributaries is discussed further below.

The depth of a stream bed has an important influence on the groundwater system adjacent to the stream and to the catchment water balance. In the modelling work to date, stream beds have been set at a depth 2 m below the land surface in all cases because there was no objective data set that allowed differentiation between streams and case study areas. However, during the course of this project, a number of stream bed cross-sections were surveyed (by DPI Broadford) in both case study areas. The results of this work are summarised in Appendix B. The data set provides a basis to set the depth of the streams as follows:

- Gardiner Creek, base of stream bed **2.0 m** the below land surface (all cross sections show a stream bed depth of about 2 m except the one on the downstream edge of the model)
- Hamilton Creek, base of the stream bed **2.5 m** below the land surface
- Dry Creek, base of the stream bed **4.0 m** below the land surface

Model sensitivity to values of stream bed/drain conductance was evaluated. It was found that stream flow was sensitive to increasing conductance to a certain level, thereafter further increases in conductance had little effect on stream flow. At high values of conductance the stream flow is most likely to be controlled by groundwater flow between [a model cell with a stream] and [a neighbouring cell with no stream]. A comparison of modelled stream flow with the estimates from stream gauges allowed selection of intermediate conductance values of 2 m^2/day and 5 m^2/day for Gardiner Creek and Hamilton/Dry Creek case study areas respectively.

Some tributary streams were added into the groundwater models as streams (mentioned above). In addition to this, many drain cells were set at the land surface in a buffer around all modelled stream lines to further represent small tributary streams. These ‘land surface drains’ only affect the groundwater flow if the watertable reaches the land surface. The surface drains were also used in the models in the South West Goulburn project Part 1, but in Part 2 of the project they are more systematically aligned with modelled stream lines. The ‘surface drains’ improve the realism of the groundwater model and account for runoff in small depressions and gullies. Flow in these drains can be considered to represent runoff and ‘exfiltration’ from saturated areas during storm events, a process that typically occurs from low lying areas next to drainage lines (Pilgrim and Cordery, 1993). One important difference between Part 1 of the project and Part 2 is that the flow modelled in the ‘surface drains’ was considered to be part of baseflow in Part 1 and is considered to be a component of surface runoff in Part 2. This small change in conceptualisation is in agreement with the above argument.

4.5 Task 5d: Sensitivity to the boundary conditions in the groundwater model

This task considers the sensitivity of the model results to the groundwater model boundary conditions at the edges of the case study areas. In particular, are the boundary conditions influencing the modelled effectiveness of afforestation? Is this influence unreasonable?

The ‘general head boundary’ condition (GHB) offered in MODFLOW is used at the edges of the groundwater models for the two case study areas. The edges of the models were taken to be the surface water catchment boundaries and in most areas these boundaries will approximately coincide with the groundwater catchment boundaries. Therefore no significant groundwater flow is expected across these boundaries. A GHB boundary condition was used because it enhances the model stability and because the input parameters can be adjusted to reduce the groundwater flow at the model edges.

This task considers the effects of the GHB boundaries on the modelled effectiveness of afforestation. Two changes were made to the GHB boundaries in the Hamilton-Dry case study area. The first reduced the conductance at the boundary by an order of magnitude, the second lowered the groundwater head input to the GHB boundary condition by 10 m. The model was run for current land use conditions and for 45 % tree cover to evaluate the effect of the boundary condition on the difference between these two land uses.

Figure 4-7 presents the predicted stream baseflow for three sets of GHB boundary conditions and Figure 4-8 presents the difference in baseflow between the two land use conditions. There are some small differences in the outputs between the three applications of the GHB boundary but these do not affect the conclusions about the effectiveness of tree planting on reduction of salt load.

- **Figure 4-7 Stream baseflow output by MODFLOW for two land use conditions and three different configurations of the GHB boundaries at the edge of the model.**

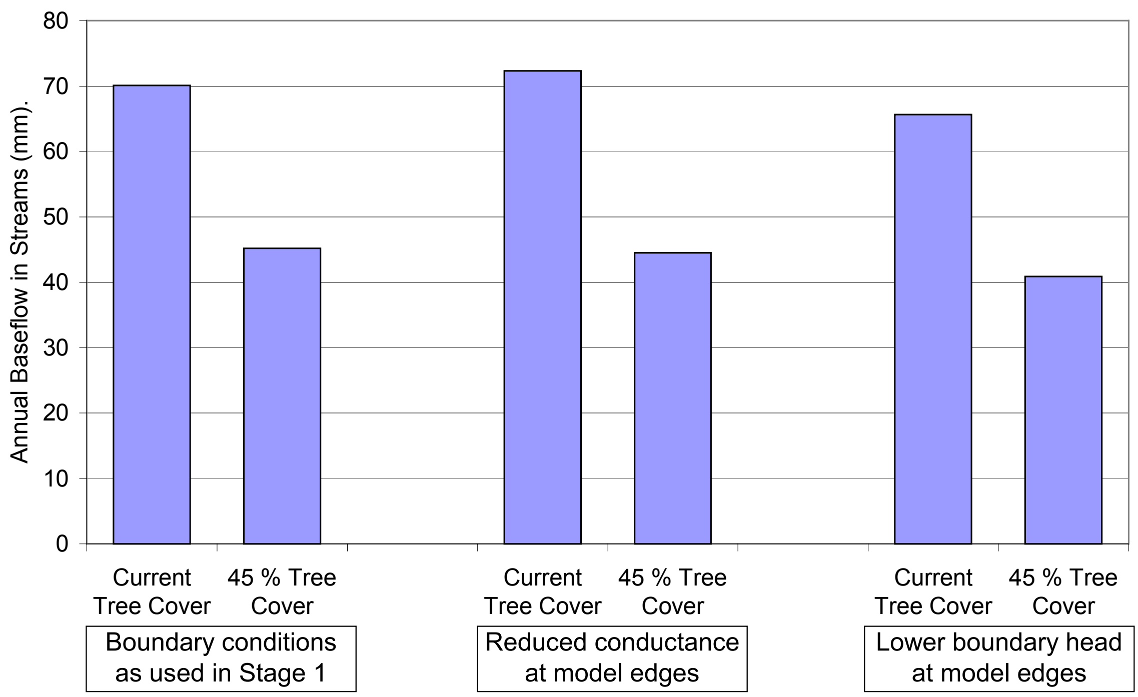
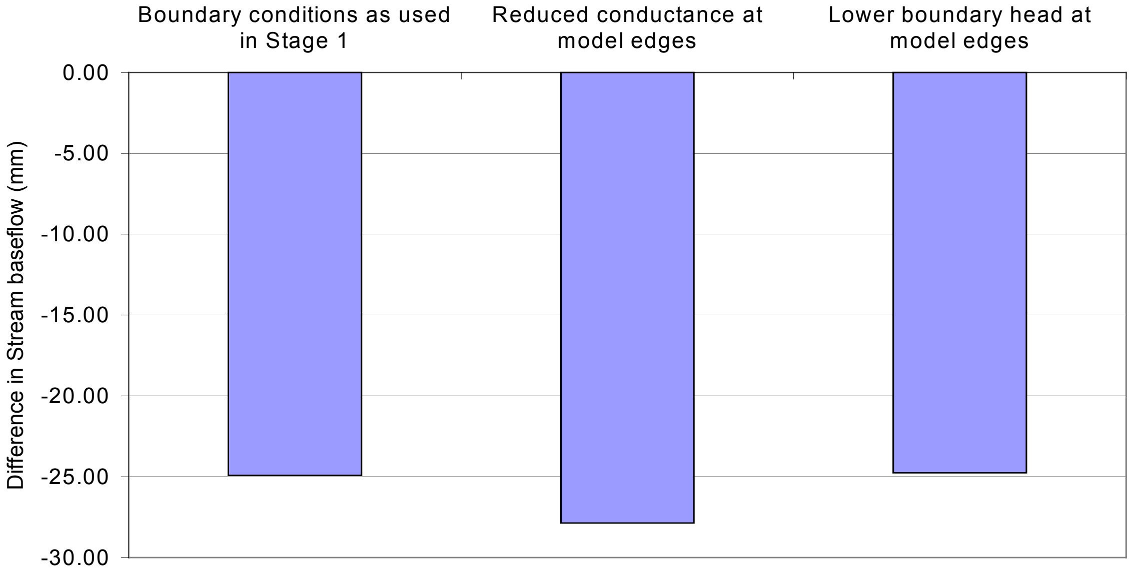


Figure 4-8 Difference in stream baseflow between current land use and 45 % tree cover for three applications of the GHB boundary condition. (See also Figure 4-7)

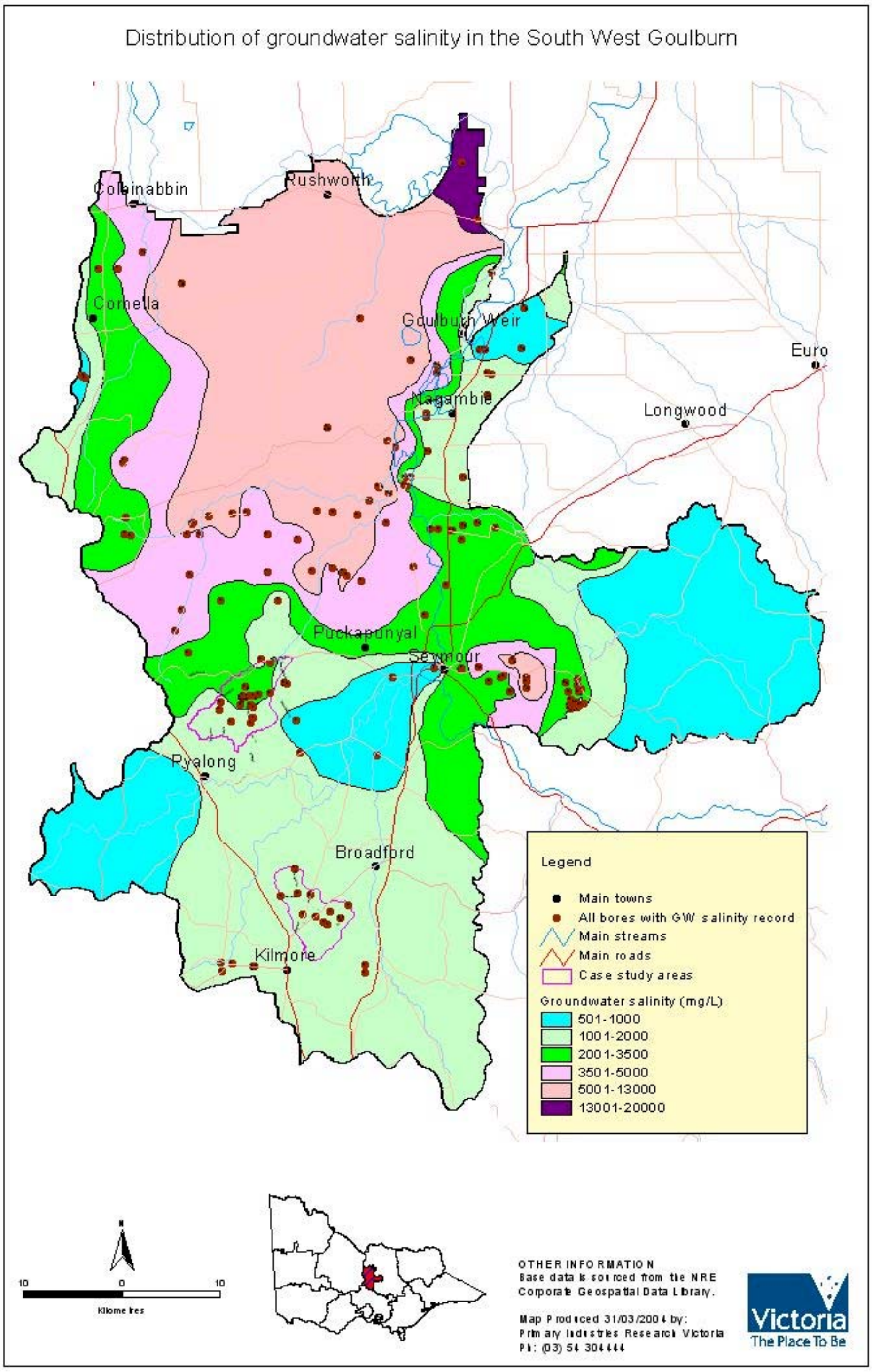


4.6 Task 6a: Sensitivity to Groundwater Salinity

Groundwater salinity data from 207 bores across the South West Goulburn have been consolidated in Figure 4-9. The map has been prepared by PIR Vic (Frankston) for this project and uses geology as a basis for extrapolation into areas with few or no groundwater bores.

The modelling approach described in this report and the report for Part 1 (Cheng et al., 2003) makes the assumption that the groundwater salinity in all parts of the case study areas (other than groundwater discharge areas) is 1000 mg/L. Figure 4-9 supports the use of 1000 mg/L as the groundwater salinity in the case study areas but indicates that much higher groundwater salinities occur in other parts of the South West Goulburn.

- **Figure 4-9 Groundwater Salinity at the watertable in the South West Goulburn.**



Task 6a tests the sensitivity of the model outputs to groundwater salinity in both parts of the MCS model (i.e. the soil profile model and the groundwater model). The component models are run using a groundwater salinity of 3000 mg/L rather than the 1000 mg/L used in all other model runs.

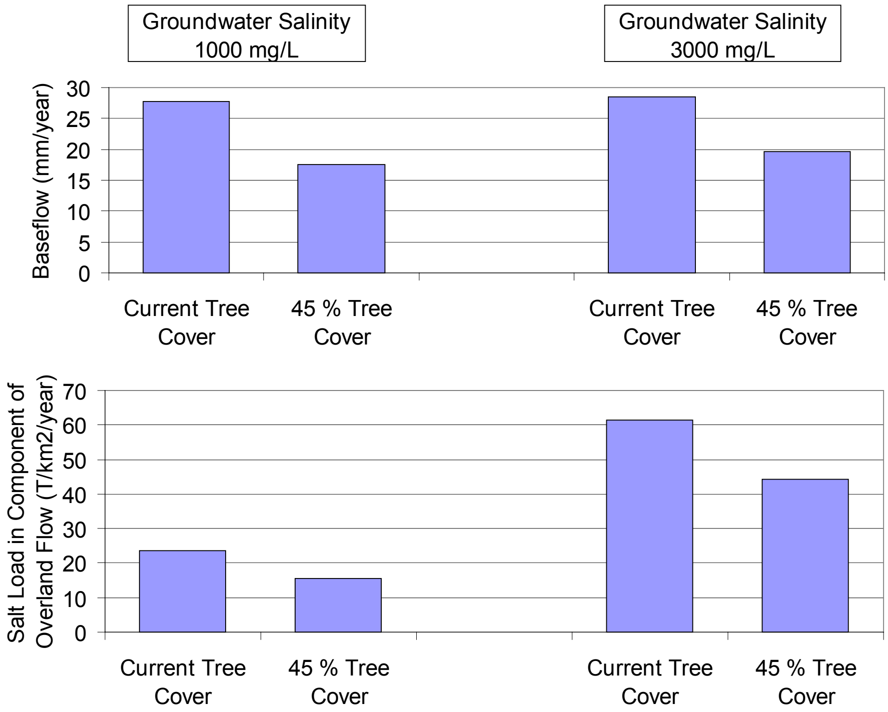
There are several inputs required to calculate a catchment salt load, one important input is the baseflow salinity. In Part 1 of the South West Goulburn project, baseflow salinity was taken as the output from an analysis of stream gauge data. For Gardiner Creek baseflow salinity was 520 mg/L and for Hamilton/Dry it was 335 mg/L. These salinities reflect the contribution to baseflow of water volumes other than 'pure groundwater' that we are assuming has an average salinity of about 1000 mg/L. This type of analysis of stream gauge records has not been undertaken in an area where we expect the groundwater salinity to have an average value of approximately 3000 mg/L and therefore the baseflow salt load can not be calculated in this sensitivity test. However, it would not be unreasonable to assume (as a first estimate) that baseflow salinities would be approximately three times larger from an area with a groundwater salinity three times greater. Therefore, equal baseflow volumes would suggest that salt loads would be three times higher.

Salt wash-off from land surfaces is another important process contributing to salt load, the first component of salt wash off is estimated as a function of the depth to watertable the second component is an output from the groundwater model. The estimated baseflow volume and the first component of salt wash-off are shown in Figure 4-10 and Figure 4-11 for case study areas Gardiner Creek and Hamilton/Dry Creek respectively. These figures suggest that in areas with a groundwater salinity of 3000 mg/L, salt loads and the change in salt load due to afforestation is between 2 and 3 times larger than it is for areas with a groundwater salinity of 1000 mg/L.

The effects of a groundwater salinity of 3000 mg/L on soil salinity in the root zone are also important. The initial soil salinity conditions of profiles in this Task were the same as they were for the 1000 mg/L case. However, it was found that the soil profiles did not always reach equilibrium soil salinity values even after 100 years of simulation. Figure 4-12 is an example of a time series of yearly average root zone salinity for trees growing in an area with an underlying groundwater pressure equivalent to a depth to watertable of 0.5 m. This clearly shows an increase in salinity with time indicating that under equilibrium conditions the salt load would be expected to be a little larger than estimated in Figure 4-10 and Figure 4-11. The soil salinity in Figure 4-12 is shown to be as high as 14 dS/m, and would be expected to have significant impacts on tree health, tree water use and may result in the death of some trees. These types of effects are not well accounted for in the MCS model as it is applied here.

These results indicate that salt load reduction in tonnes per year is likely to be greater in areas with higher groundwater salinity. However, where watertables are shallow, soil salinity in the tree root zone will increase more quickly and reach a higher equilibrium value. In the South West Goulburn higher groundwater salinities are commonly associated with shallow watertables. Further investigation is required to better understand the opportunities for salt load reduction in catchments with high groundwater salinity.

Figure 4-10 Gardiner Creek: Comparison of the effects of groundwater salinity on different components of salt and water balance.



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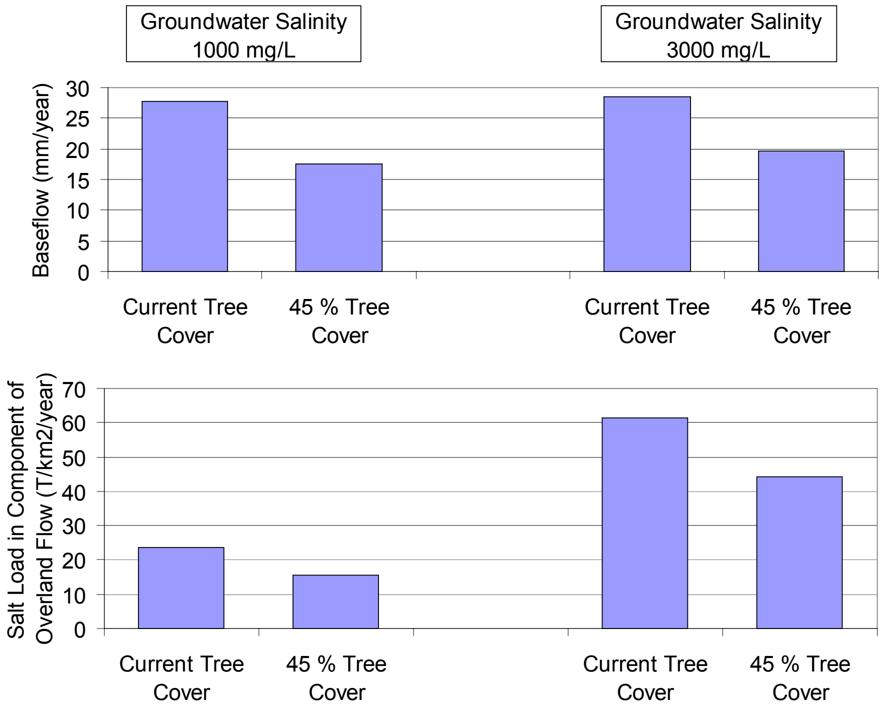
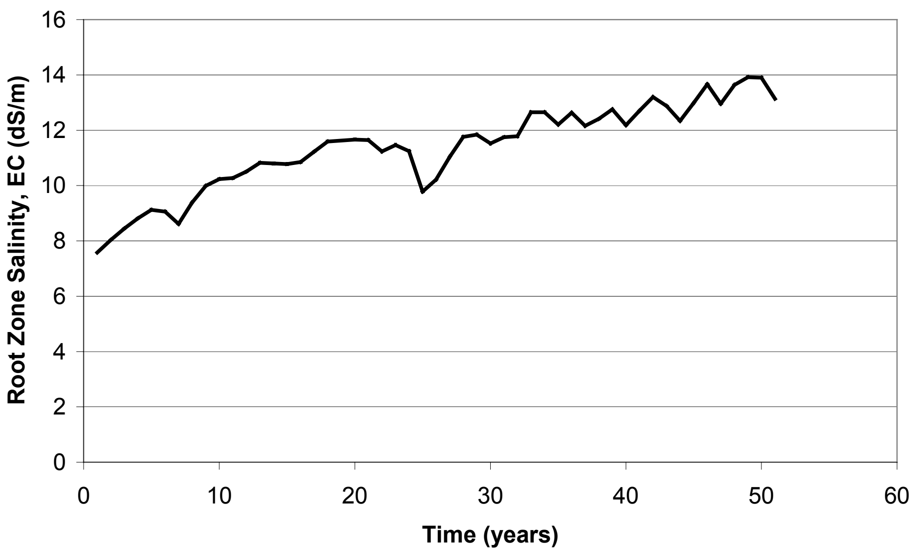
- **Figure 4-11 Hamilton/Dry Creek: Comparison of the effects of groundwater salinity on different components of salt and water balance.**



- **Figure 4-12 Gardiner Creek: Time series of root zone salinity for a land use of trees with an underlying groundwater potential equivalent to a watertable depth of 0.5 m.**



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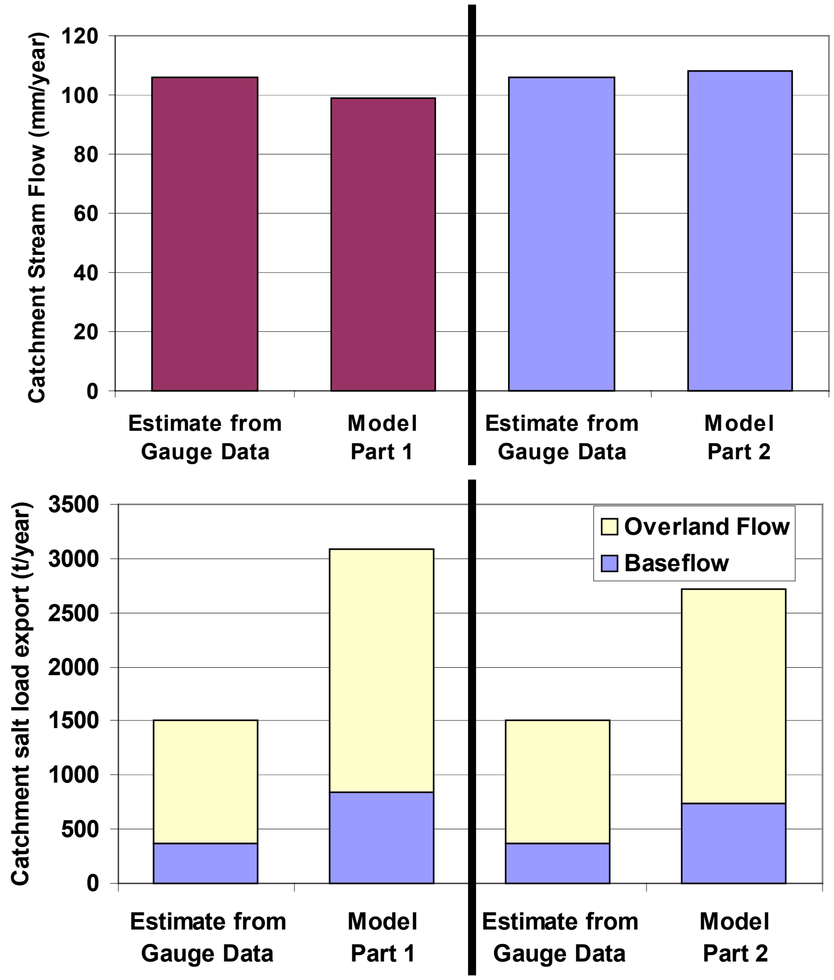
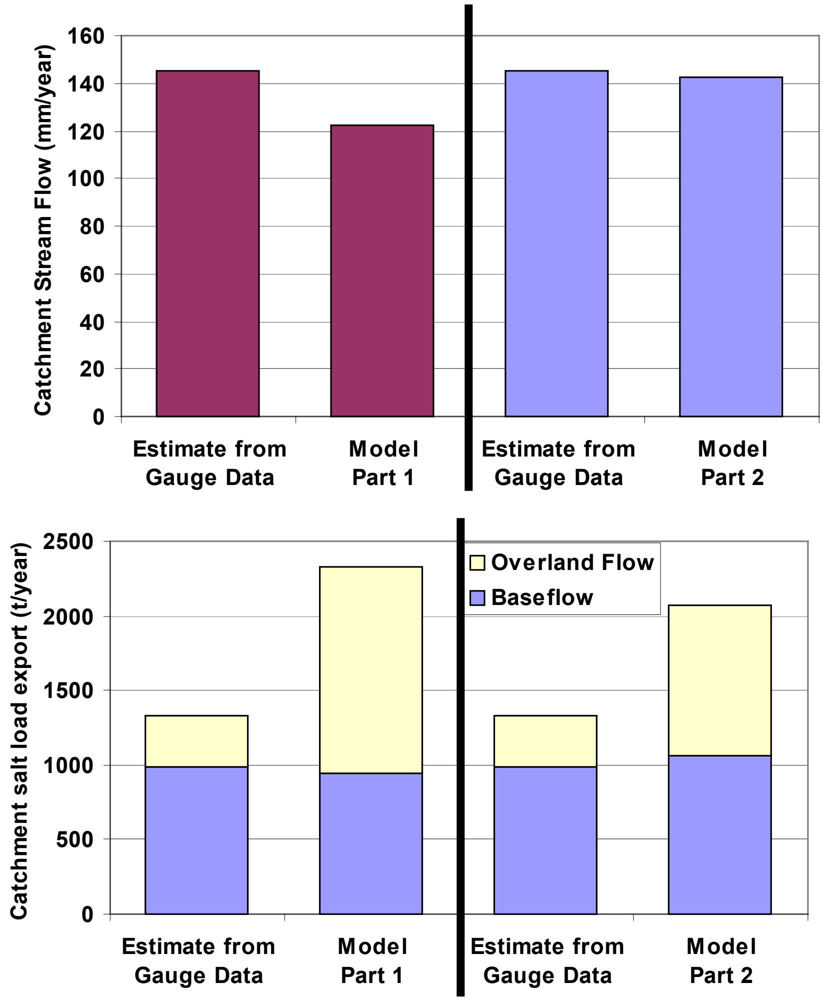
4.7 Task 6b: New Model developments in Case Study Areas

The changes to the MCS model that were presented in Sections 4.3, 4.4 and 4.5 were implemented in the latest versions of the model for the case study areas. These changes resulted in a small improvement in the agreement between stream flow and salt load estimates from the model and from stream gauge data (Figure 4-13 and Figure 4-14).

- **Figure 4-13 Gardiner Creek: comparison of stream flow and salt load as modelled in Part 1 and Part 2 of the project. Model results are also compared with estimates from the stream gauge network.**



- **Figure 4-14 Hamilton/Dry Creek: comparison of stream flow and salt load as modelled in Part 1 and Part 2 of the project. Model results are also compared with estimates from the stream gauge network.**



The agreement between the estimate of salt load from the stream gauge network and from the MCS model is still not as good as desired. The discussion in Section 3.1 provides further context to this issue, both the estimate from the gauges and from the model have associated uncertainty.

An important step to improving the MCS model representation of salt transport would be a more detailed treatment of runoff in storm events. A methodology is already applied within the MCS model to allow for distribution of rain within a day (Boughton, 2000). This allows for a random distribution of storm events that is consistent with more detailed measurements of rainfall during storms. However, it is suggested that surface runoff during storm events is still poorly modelled and that improvements to modelled salt load would occur if modelled runoff was improved.

A suggested approach is to look at about 10 'average' storm events in detail. Analysis of stream flow records would aim to estimate surface runoff (quickflow) and baseflow associated with each storm event and hourly rainfall records could be extracted using Melbourne rainfall radar imagery. (Sinclair Knight Merz have a particularly strong background in the rainfall radar data, and two storm events have already been investigated for the South West Goulburn case study areas.) This work would provide a quick and objective basis to adjust (fine tune) the hydraulic properties of the soil profiles and improve the representation of runoff in the MCS model.

5. Locating Native Vegetation/Trees in the South West Goulburn to Reduce Salt Load

The primary objective of the second part of the South West Goulburn project is to identify areas across the whole South West Goulburn (SWG) with the potential to provide long term salt load reduction through native revegetation. The context for salt load reduction is the need to meet 'End of Valley' salt load targets for the Goulburn River. This section describes the approaches used and summarises the relevant results.

5.1 Selection of Spatial Data Sets

Mark Cotter (DPI, Benalla) has led the development of GIS rules to identify promising locations for native vegetation/forest across the South West Goulburn. The methodology was discussed at two meetings at Sinclair Knight Merz in Melbourne (on 12th February and 2nd April) and at the project workshop in Trawool on 11th May. Xiang Cheng (DPI Frankston) has also contributed to this work.

There are many factors affecting salt export from a catchment, including the distribution of the depth to watertable, groundwater salinity, topography, climate, land use and soil characteristics. It is not practical to use all these factors because some of data sets are not reliable others are not available in a suitable format. The following spatial data sets were selected for use after consideration of what was available.

- depth to watertable (DWT)
- topographic characteristics (topographic wetness index, TWI)
- characteristics of groundwater recharge
- existing tree cover.

Depth to watertable can have a significant impact on tree water use and growth. When the watertable is shallow (e.g. < 5 m), trees may have access to groundwater and use more water in the short-term. However, this potentially causes salt accumulation in the root zone, particular in areas where the groundwater is saline. When trees take up water from or near a watertable, groundwater flows towards the roots carrying salts, which can accumulate in the root zone and limit transpiration and growth. The long-term sustainability of tree growth over shallow watertables has been well documented (Thorburn, Walker & Jolley 1995; Morris 1999; Silberstein et al. 1999). The effect was also noted in the model outputs from Stage 1 of this study (Cheng et al. 2003).

The map of depth to watertable used in this study was generated by CLPR (2002) as a part of the NAP Catchment Analysis Tool project. The watertable across the region was estimated by applying the relationships between the reduced water levels and the elevation of the natural surface on the 100 m digital elevation model. The relationships were derived using all reliable bore data available in the Goulbourn Broken Dryland. The procedure to produce the watertable map was described by CLPR (2002).

Topography has significant effects on surface run off and throughflow (or interflow). Increased slope encourages lateral movement of water at the expense of vertical seepage. Runoff and/or interception tend to increase, and recharge decrease, on more sloping sites. In this study, the topographic wetness index (TWI) was used to account for the influence of topographical attributes (e.g. slope gradient and landscape position).

TWI is defined as $ln(A/\tan\beta)$, where *ln*() is the natural logarithm, A is the area drained per unit contour or the specific area, and $\tan\beta$ is the slope. This TWI was computed from the 100 m cell digital elevation model. Regions of the landscape that drain large upstream areas or that are very flat, give rise to high values of TWI; thus areas with the highest values are most likely to become saturated during a rain event and are most likely to be areas that contribute accumulation of surface runoff and groundwater recharge (Hornberger & Boyer 1995). Areas within the basin possessing the same value of the topographic wetness index are likely to have similar hydrological behaviour.

It is widely accepted that dryland salinity is a consequence of rising groundwater levels caused by increased recharge. This has resulted from extensive clearing of deep-rooted native vegetation and replacement with a range of crops and pastures that use less water. Given the current understanding of the causes of secondary salinity, it is a logical action to plant trees in high recharge areas to restore catchment water and salt balance, consequently reducing salt export from the catchment. In this study, a map of potential recharge produced by Cheng (2004) was used in the GIS process. The potential recharge was estimated by taking into account most significant contributing factors to recharge, including soil characteristics, groundwater flow systems and topography. Seven classes of potential recharge were used in the mapping exercise: very high, high, moderate-high, moderate, low-moderate, low and very low.

In addition to the three key factors discussed above, the existing tree cover was included in the GIS analysis in this study. Retaining existing tree cover has formed an important part of the catchment management strategies in the Goulburn Broken Catchment. Thus, the areas with existing tree cover are considered as the ‘high priority’, regardless of the values of the other three key factors. The spatial data set ‘tree100’ in the DPI/DSE Corporate Geospatial Data Libraries (CGDL) was used for this study.

The case study areas (Gardiner and Hamilton/Dry) were used to trial the application of these data sets in the identification of locations for native vegetation/forest. In the development phase, two approaches are used to identify areas well suited to use of native vegetation for control of salt load export. The first approach is most strongly influenced by the spatial coverage of depth to watertable

(DWT) and the second is most strongly influenced by topographic wetness index (TWI). The current tree locations and biodiversity issues are not used in the development phase.

5.2 Development Phase: Application in Case Study Areas

The case study areas were used to investigate differences in salt load export that result from a range of different spatial distributions of native vegetation/trees across the model area. The effect of increasing the fractional cover of trees is also investigated.

These investigations aim to improve the selection of areas within the whole South West Goulburn (SWG) to deliver the best salt load benefits under the establishment of native vegetation.

The tree cover scenarios investigated include the approaches described above (strongly influenced by either DWT or TWI) and those used in Part 1 of the project. In the Gardiner Creek case study area the scenarios considered are:

- Tree cover scenarios strongly influenced by depth to watertable (DWT), and not considering current tree location or biodiversity issues:
  - DWT38 – 38 % tree cover
  - DWT54 – 54 % tree cover
- Tree cover scenarios strongly influenced by topographic wetness index (TWI) , and not considering current tree location or biodiversity issues:
  - TWI34 – 34 % tree cover
  - TWI53 – 53 % tree cover
- Tree cover scenarios that were used in Part 1 of the South West Goulburn Project
  - Current land use (9.7 % tree cover, estimated with the aid of Digital Globe images)
  - 30 % tree cover (tree area increased at locations identified for biodiversity outcomes without encroaching on areas of native pasture)
  - 45 % tree cover (further increase in the area of trees by enlarging areas already identified and by extending to a range of catchment locations, areas of identified native pasture were not included as tree cover)
  - 60 % tree cover (further increase in the area of trees by enlarging areas already identified and by extending to a range of catchment locations, areas of identified native pasture were not included as tree cover)
  - 45 % relocation (45 % tree cover relocated to lie along stream depressions, with no consideration of areas of identified native pasture)

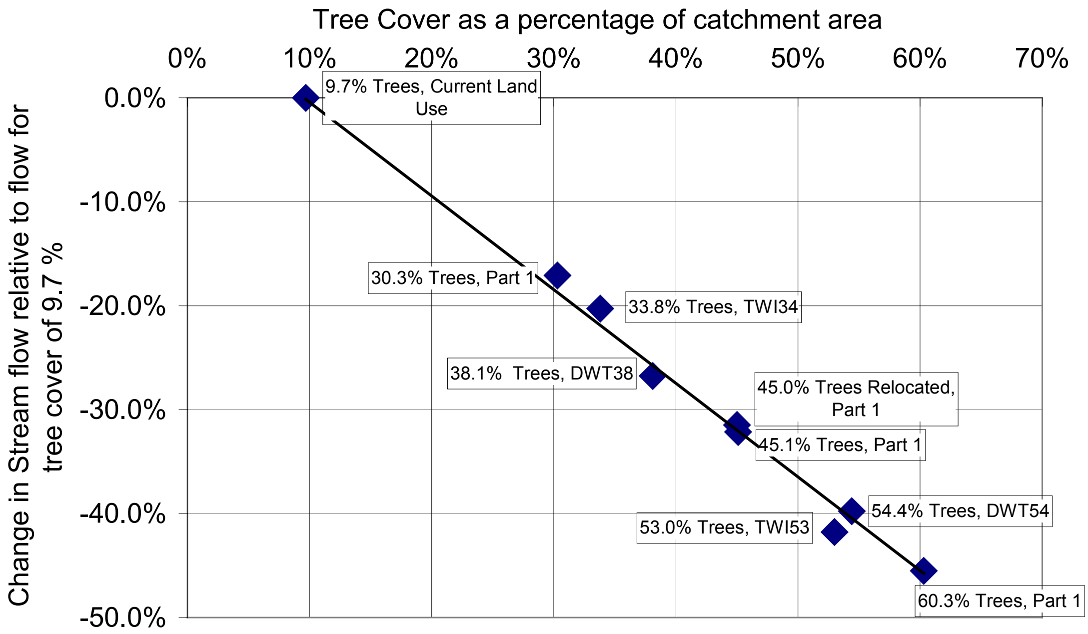
In the Hamilton/Dry Creek case study area the scenarios considered are:

- Tree cover scenarios strongly influenced by topographic wetness index (TWI) , and not considering current tree location or biodiversity issues:
  - TWI34 – 34 % tree cover
  - TWI48 – 48 % tree cover
- Tree cover scenarios that were used in Part 1 of the South West Goulburn Project (same description for Gardiner Creek)
  - Current Land Use (8.8 % tree cover)
  - 30 % Tree Cover
  - 45 % Tree Cover
  - 60 % Tree Cover
  - 45 % Tree Cover - Relocation

The spatial distribution of trees in both case study areas and under the above scenarios is presented in Appendix C.

Figure 5-1 to Figure 5-4 show the range in the response of stream flow and salt load export to tree cover over the range of scenarios described above. The data point labels correspond to the descriptions in the preceding paragraphs.

- **Figure 5-1 Gardiner Creek: change in modelled stream flow versus tree cover. The line shown is the linear regression line that passes through the point representing current conditions (i.e. stream flow = 108 mm/y). The data point labels are described in the text.**



- **Figure 5-2 Hamilton/Dry case study area: change in modelled stream flow versus tree cover. The line shown is the linear regression line that passes through the point representing current conditions (i.e. stream flow = 149 mm/year).**

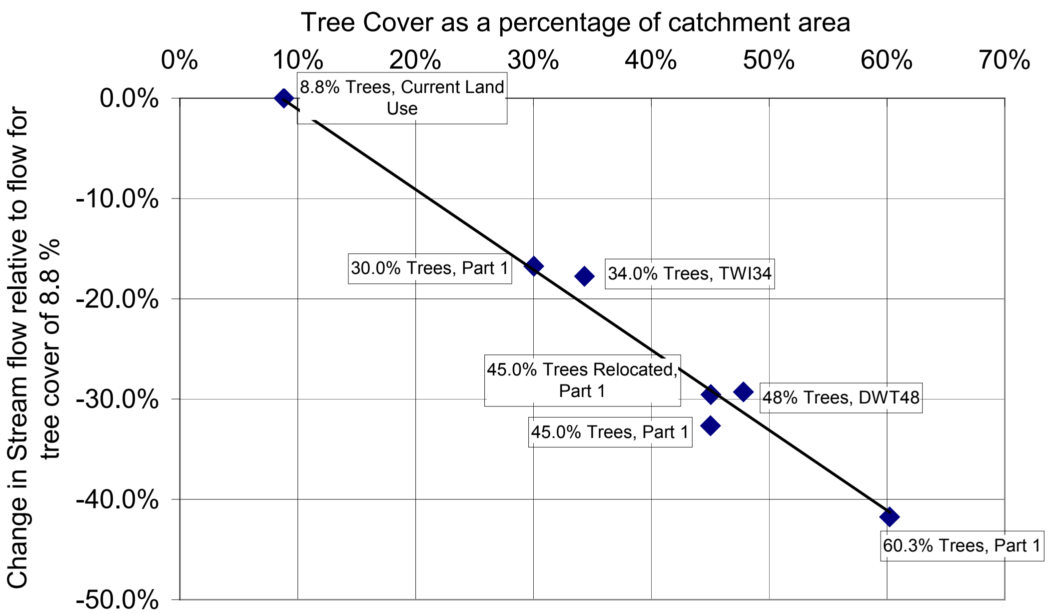


Figure 5-1 and Figure 5-2 show a rather linear response of modelled stream flow to increasing cover with native vegetation/trees in both case study areas.

Figure 5-3 and Figure 5-4 show the effects of tree cover scenarios on modelled salt load export. Tree cover has a slightly larger effect on salt load than it does on stream flow and the effects are a little more variable between scenarios.

In the following section we would like to estimate the effects of tree cover scenarios across the SWG and this requires the response of a subcatchment to a scenario to be estimated as a function of the current tree cover and the proposed tree cover (proposed >= current). A quick evaluation of Figure 5-1 to Figure 5-4 indicates that changes in both stream flow and salt load as a function of tree cover can be estimated using straight lines. The lines shown in the Figures are fitted by regression and pass through the point representing current conditions.

The x axis used in Figure 5-1 to Figure 5-4 (catchment tree cover %) is normalised in Equation [5.1] below to facilitate application to catchments with a range of current tree cover conditions.

$$y = -Kx \qquad [5.1]$$

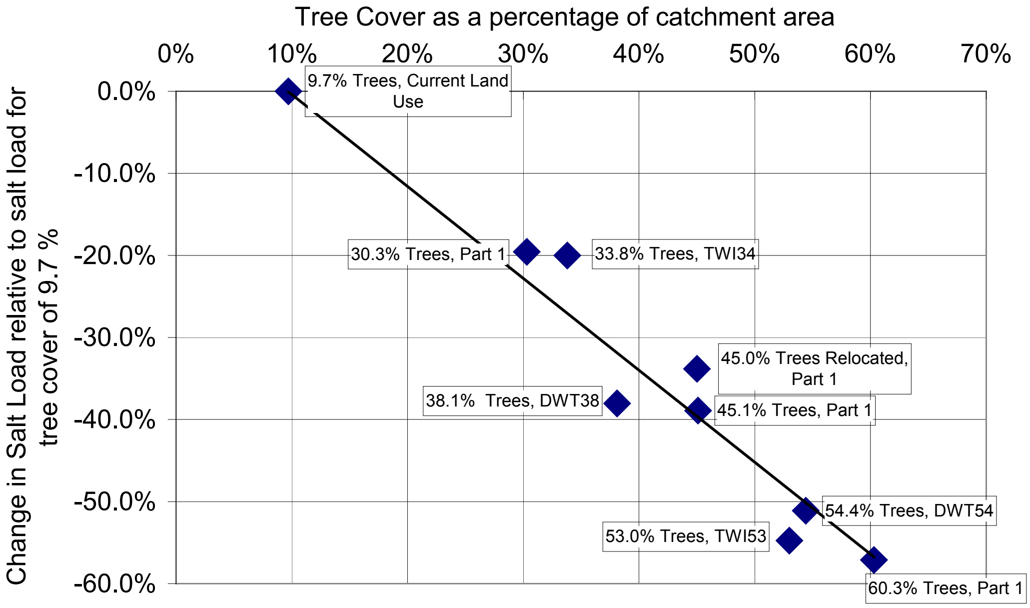
where: x = the new tree cover as a percentage of the catchment area currently without trees
= (Proposed tree cover % - Current tree cover %) / (100 % - Current tree cover %)
= has a value between 0 % and 100 %
y = change in stream flow or salt load as percentage of current value
= $(y_{new} - y_{current})/y_{current}$ *100%
= has a value between 0 % and -100 % in these examples
K = the coefficient, fitted by linear regression

Thus for the 60 % tree cover case in Gardiner Creek, $x = (60 - 9.7)/(100 - 9.7) = 55.7$ %. The lines equivalent to those shown in Figure 5-1 to Figure 5-4 have associated K values given in Table 5.1.

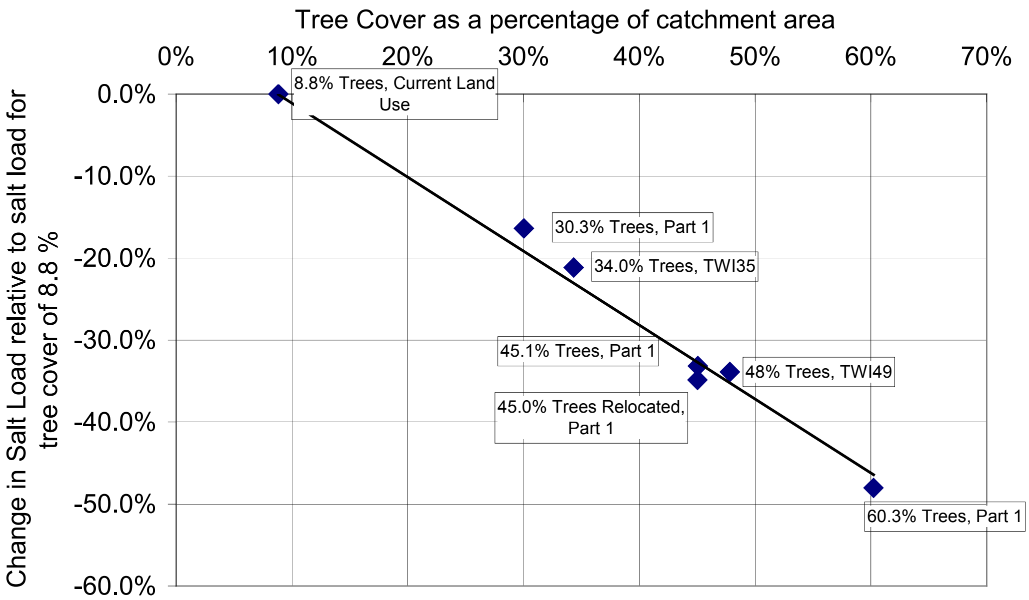
Table 5.1 The slope of the lines fitted by linear regression to Equation [5.1]. The standard error is given in parenthesis () after the *K* value.

	Value of *K* in Equation [5.1]
Stream Flow – Gardiner Creek	0.82 (0.01)
Stream Flow – Hamilton and Dry Creek	0.73 (0.02)
Salt Load – Gardiner Creek	1.02 (0.04)
Salt Load – Hamilton and Dry Creek	0.83 (0.02)

- **Figure 5-3 Gardiner Creek: change in modelled salt load export versus tree cover. The line shown is the linear regression line passing through the point representing current conditions (i.e. tree cover = 9.7%, salt load = 53 T/km²/year).**



- **Figure 5-4. Hamilton/Dry case study area: change in modelled salt load export versus tree cover. The line shown is the linear regression line passing through the point representing current conditions (i.e. tree cover = 8.8 %, salt load = 51 T/km²/year).**



5.3 South West Goulburn Tree Cover Scenarios

Four scenarios were developed on the basis of the above information and the outcomes of the workshop held on 11th May at Trawool.

Scenario 1:

This is the maximum tree cover scenario that was considered. The following rules were used to identify areas that would be suited to tree cover establishment with the purpose of salt load reduction. The areas identified are:

- Areas where trees are currently present ;
- Areas where the current depth to watertable is > 10 m;
- Areas considered to be moderate recharge areas with a depth to watertable > 5 m;
- Areas with a depth to watertable between 5 m and 10 m and a topographic wetness index > 0.25
- Areas with a depth to watertable between 2 m and 5 m and a topographic wetness index < 0.2

Scenario 2:

The areas identified for native vegetation/tree cover are:

- Areas where trees are currently present ;
- Areas where the current depth to watertable is > 10 m;
- Areas considered to be moderate recharge areas with a depth to watertable > 5 m;
- Areas with a depth to watertable between 5 m and 10 m and a topographic wetness index > 2.0
- Areas with a depth to watertable between 2 m and 5 m and a topographic wetness index < 0.01

Scenario 3:

The areas identified for native vegetation/tree cover are:

- Areas where trees are currently present ;
- Areas where the current depth to watertable is > 10 m, and topographic wetness index > 0.1;
- Areas considered to be moderate recharge areas with a depth to watertable > 5 m;
- Areas with a depth to watertable between 5 m and 10 m and a topographic wetness index > 5.0
- Areas with a depth to watertable between 2 m and 5 m and a topographic wetness index < 0.01

Scenario 4:

The areas identified for native vegetation/tree cover are:

- Areas where trees are currently present ;

- Areas where the current depth to watertable is > 10 m, and topographic wetness index > 1.0;
- Areas considered to be moderate recharge areas with a depth to watertable > 5 m;
- Areas with a depth to watertable between 5 m and 10 m and a topographic wetness index > 5.0
- Areas with a depth to watertable between 2 m and 5 m and a topographic wetness index < 0.01

The spatial distribution of tree cover across the SWG is presented in Appendix D for these scenarios.

5.4 Salt Load Reduction at the 'End of Valley'

An important ongoing consideration of these scenarios is the salt load reduction that would result at the 'End of Valley' point for the Goulburn River. Estimation of this salt load was not included in the proposal for Part 2 of the South West Goulburn project, but was able to be added to the work plan because of related work being undertaken concurrently by Sinclair Knight Merz.

The approach described below for estimating salt load at the end of valley is indicative only. A number of contributing factors are not able to be considered in the analysis. Nevertheless it provides a valuable context in which to compare the options for salt load reduction in the Goulburn Valley.

Firstly, the SWG region is separated into the subcatchments as they are used in the REALM model. The boundaries of these subcatchments are shown in Appendix D (note that these subcatchments do not include all of the SWG project study area). The area of tree cover under current conditions and under each of the four scenarios was calculated through analysis of the spatial data sets. Table 5.2 presents the results of this analysis.

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Table 5.2 Tree cover in the REALM subcatchments of the South West Goulburn under current conditions and under the four proprosed scenarios of tree cover.

REALM Subcatchment within South West Goulburn	Area (km^2)	Current Tree Cover	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Goulburn Weir (mid SW Goulburn to Goulburn Weir)	828	**32%**	62%	49%	42%	41%
Major Creek	289	**47%**	70%	53%	49%	47%
Hughes Creek	476	**14%**	94%	91%	83%	36%
Gardiner Creek	178	**21%**	57%	39%	32%	24%
Mid Goulburn (from Trawool halfway to Goulburn Weir)	486	**21%**	55%	44%	36%	29%
Whiteheads Creek	52	**2%**	65%	57%	54%	50%
Sugarloaf Creek	608	**10%**	75%	62%	55%	20%
Sunday Creek	334	**33%**	75%	63%	54%	38%
Total Tree cover in the South West Goulburn as used by the REALM model of the Goulburn River.	3251	**24%**	69%	57%	50%	33%

The REALM model is currently used in the Victorian part of the Murray Darling Basin to investigate the flow and salinity in the major river systems. It is used to evaluate the effects of changes in flow and salt load in subcatchments on end of valley targets that have been identified by the Murray Darling Basin Commission (MDBC). We apply the REALM model of the Goulburn River to investigate the effects of the tree cover scenarios in the South West Goulburn on the salt load at the end of valley.

The effects of a tree cover scenario on stream flow out of a subcatchment are estimated using Equation [5.1]. Equation [5.1] is used to calculate a percentage reduction in stream flow for each subcatchment and each scenario. Stream flow from a subcatchment is adjusted by uniformly reducing daily flow using the value $\boldsymbol{K} = 0.9$ (this is a rounded average value of $\boldsymbol{K}$ values for flow and salt load given in Table 5.1). Salt load is reduced by the same factor when the daily stream salinity value is left unchanged. The adjusted daily values of stream flow in each scenario are then used as four new sets of inputs to the REALM model and the outputs are compared with the default values.

Table 5.1 suggests an increased tree cover may result in a larger percentage reduction in salt load than in stream flow. To evaluate the effect of a larger reduction in salt load the daily stream salinity value was uniformly reduced in addition to the stream flow reduction in Scenario 3. In this case $\boldsymbol{K} = 1.0$ for salt load and the result is plotted below as an error bar (Figure 5-5).

Figure 5-5 shows the reduction in salt load in the Goulburn River at Goulburn Weir and downstream at Murchison respectively. During the irrigation season, significant water volumes are diverted from Goulburn Weir to the Shepparton East channel and to Waranga Basin. In contrast to the absolute values shown in this figure the percentage reduction in salt load is greater at Murchison than it is at Goulburn Weir.

Figure 5-5 Change in salt load carried by the Goulburn River as modelled by REALM for the four scenarios of tree cover. The error bars shown for Scenario 3 indicate a possible range in salt load reduction.

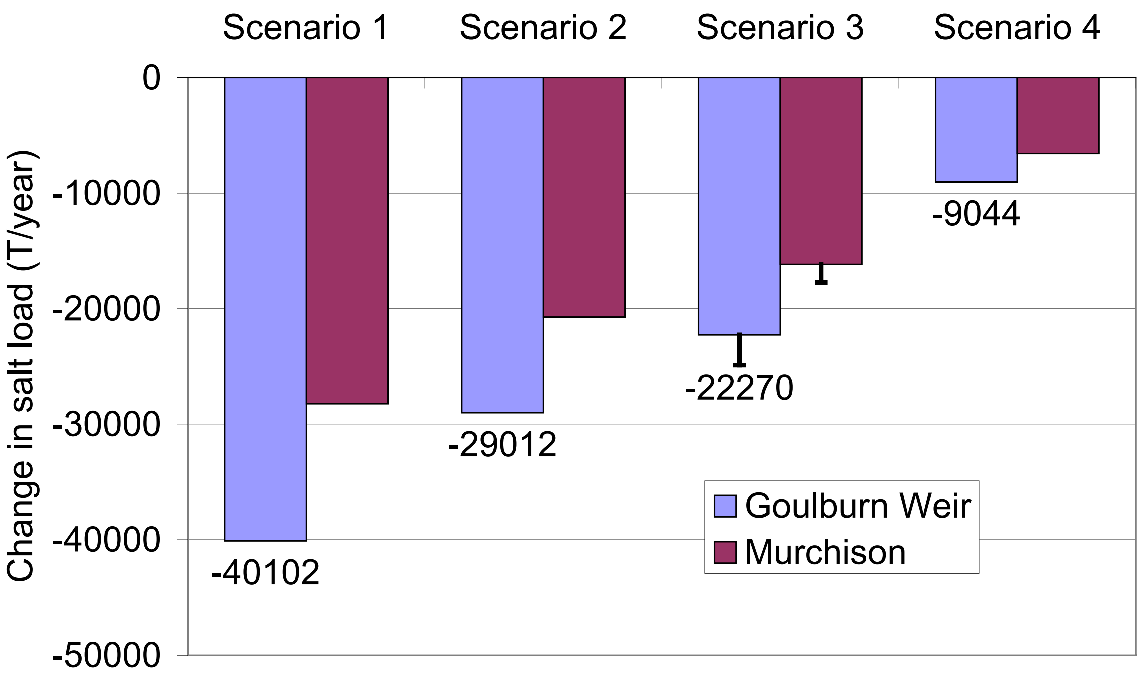

Figure 5-6 and Figure 5-7 show the change in flow and salt load in the Goulburn River at Murchison as a function of the tree cover across the South West Goulburn. The response of stream flow and salt load to tree cover is so close to linear because Equation [5.1] was used to estimate these effects on a subcatchment basis.

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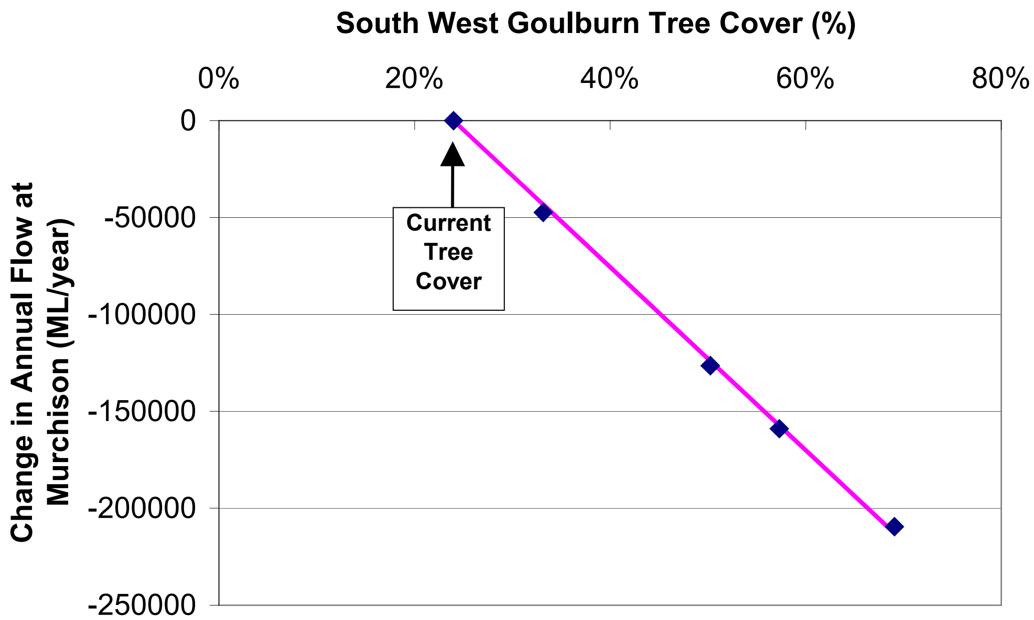
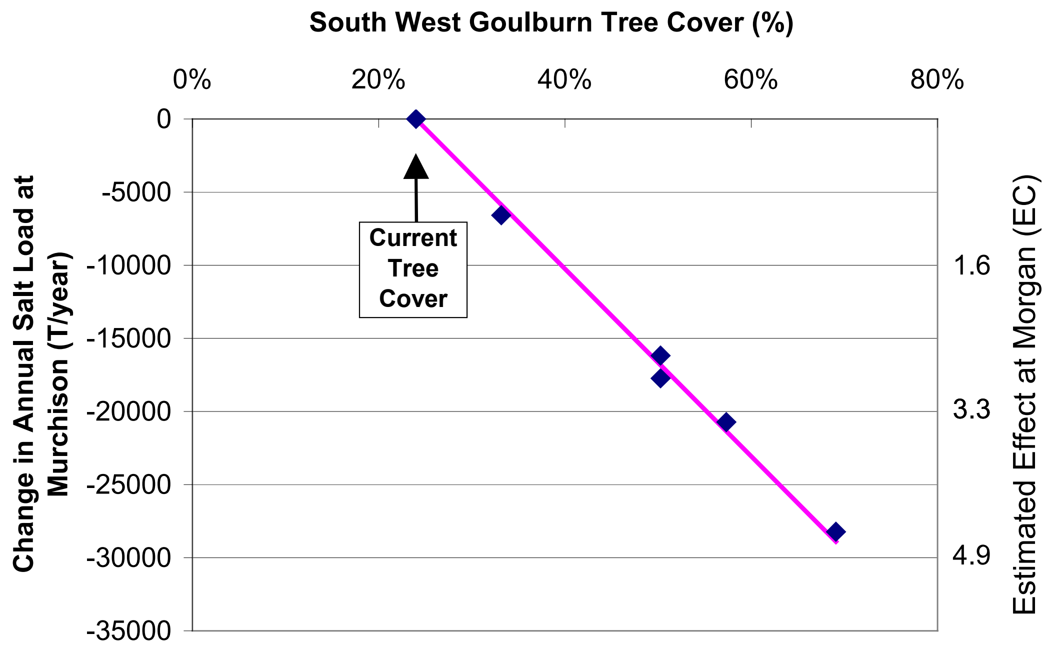
- **Figure 5-6 Change in modelled annual flow at Murchison vs tree cover in the South West Goulburn.**



- **Figure 5-7 Change in modelled Salt Load at Murchison vs tree cover in the South West Goulburn. An estimate of the effect on EC at Morgan is given on the axis on the right.**



Some context to these results is provided by the details of subcatchment flow and salinity that are used in the REALM model and are also presented in Appendix E. The daily data series runs from July 1974 to July 2000 and a significant part of the data set for the South West Goulburn is estimated (gauges do not exist or are unreliable). Over this period, the REALM model indicates that 31 % of the salt load at Goulburn Weir is exported from the SWG.

It is interesting to note that the largest contributing salt loads in the SWG come from Sugarloaf Creek (13900 T/year) and Hughes Creek (9500 T/year). These two subcatchments also have relatively high salt load per square kilometre. A large increase in tree cover occurs in the Hughes and Sugarloaf subcatchments under the scenarios of native vegetation/tree cover (Table 5.2) and this supports a significant reduction in salt load export from the SWG.

6. Further Work

The work undertaken in this Part 2 of the South West Goulburn project has identified some aspects of the MCS model and its application that are likely to benefit from further attention. Some of these aspects are listed below.

A) Analyse model outputs to estimate and map the parts of the case study areas that will be salt-affected. Analysis of catchment stream flow and salt load export are presented in this report, but the 'salt-affected area' may also differ between the scenarios considered.

B) Soil profile description and distribution of soil types to be reviewed using the latest outputs from Part 1 of the project and other recent publications. (Some small discrepancies have been noted between the spatial data set for soils used in the MCS model and the final map of soils presented in the Part 1 report)

C) Different *K* values (in Equation [5.1]) could be used for stream flow and for salt load at the scale of the South West Goulburn. Also the seasonal variation of changes in flow and salt load could be investigated to check how these variations change the effects at Goulburn Weir and Murchison. It may also be possible to differentiate between the subcatchments of the South West Goulburn in terms of salt load and stream flow using topography and soils.

D) Further develop/test the representation of the hydrology in parts of the case study areas with shallow watertables (especially in the groundwater model).

E) Investigate the process of soil salinisation in tree root zones using a two dimensional model representing a hillslope and valley. This investigation would use a transient model to allow seasonal and inter-annual variation to contribute to salt movement processes.

F) Undertake further analysis to understand the differences between the two case study areas. There are some significant differences between Gardiner Creek and Hamilton/Dry and although some of these differences have been investigated more resources could be allocated to this task.

G) Consider improvements to the representation of surface runoff in the models. This could include consideration of: (a) the input parameters to the salt wash-off module (Section 4.1), (b) the possibility of representation of an impermeable zone in the top few millimetres of the soil, (c) the use of hourly rainfall data from the Melbourne rainfall radar system. Representation of other contributing processes would also be evaluated.

H) Hydraulic conductivity of the subsoil has an important influence on the soil water balance. Any field measurements that might assist in improving our understanding of the hydraulic properties of the subsoil could lead to significant improvements of the MCS model. Hydraulic conductivity of the subsoil could be inferred through soil profile water content measurements in the field or direct field/lab measurements of hydraulic conductivity itself.

I) Select and model a third case study area with features that differ from the current two areas (for example, differences in surface geology or groundwater salinity).

This task list is not intended to be comprehensive but provides some indication of areas of investigation that would benefit from further work. Tasks **A**, **B**, **C** and **D** above represent additional tasks that are an extension of the current work. The remaining tasks are somewhat new developments that are likely to need more resources and time. The tasks could be prioritised through discussion to reflect the needs/requirements of the GBCMA.

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7. Effects of Small-Scale Groundwater Pumping Schemes on Salt Load Export

7.1 Introduction

This section describes an investigation that provides a 'conceptual model' assessment of the feasibility of small-scale groundwater pumping schemes using the MCS model. This work is a later addition to Part 2 of the South West Goulburn project authorised on 8th April, 2004. The modelling work presented here is only intended to be a pre-feasibility study and more detailed investigations would be required to make reliable recommendations about irrigated land use development at specific sites in the South West Goulburn.

The study of small scale groundwater pumping schemes is efficiently undertaken by adding groundwater pumps and irrigation using groundwater to the MCS model of the Gardiner Creek case study area. The aims of this work are:

- To provide a first-cut estimate of the equivalence in terms of effect on catchment salt load export of (a groundwater pump) and (an area in hectares revegetated with trees).
- To undertake preliminary assessment of some potential risks in these developments, for example:
  - salt accumulation in the soil profile under irrigation with saline water (1000 mg/L) and the effects on irrigated crop productivity
  - reliability of groundwater supply in the unconfined aquifer systems

7.2 Development Scenario

Vineyards and olive groves are two land uses that are beginning to be established in the South West Goulburn. Irrigated grapevines were chosen as the land use to be considered in this investigation because less information was immediately available for the characterisation and management of olive orchards.

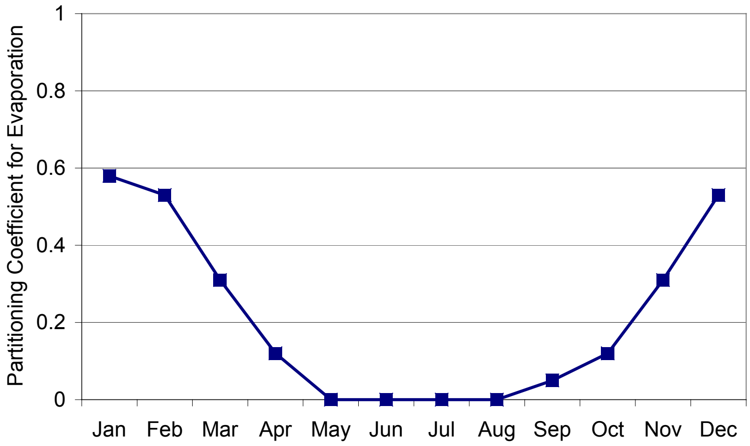
One of the primary constraints of irrigation development in these areas is the groundwater yield that is sustainable in the long term. It is thought that acceptable conditions for small-scale groundwater developments may occur in the Gardiner Creek case study area because of higher aquifer hydraulic conductivities expected around the Moormbool fault.

We speculate that development of irrigated vineyards might occur as a number of small areas of 10 to 20 ha. This type of development is consistent with the need to have a groundwater source that is sustainable in the long term. The total area of irrigated development in Gardiner Creek is taken to be 100 ha.

7.3 Irrigated Grapevines

The land uses currently represented in the model are: annual pasture, perennial pasture, native pasture and native shrubs/trees. To these dryland options, we add irrigated grapes as a land use. The annual development of a canopy for grapevines is taken from another study undertaken by Sinclair Knight Merz and is shown in Figure 7-1. The root distribution for grapevines used in the model lies mainly between the land surface and 1 metre with some roots extending to 2 m. It is similar but a little deeper than the root distribution used for native pasture.

- **Figure 7-1 The evaporation partitioning coefficient versus month of the year for grapevines. Put simply, this coefficient is the fractional ground cover of the vine canopy month by month.**



It is assumed in the model that grapevines will be irrigated with an average of 2 ML of groundwater per hectare per year and that the volume of groundwater pumped is applied to the land surface as irrigation. [Later studies could also consider evaporative loss from farm dams used to hold the groundwater.]

Grapevines are often drip irrigated on a daily basis with irrigation applied at a rate that does not meet the potential water demand (i.e. the maximum possible water use) of the crop. (This is called reduced deficit irrigation). The irrigation regime is modelled by applying irrigation at a rate of 1.3 mm/day during periods when the crop canopy is present and when the cumulative sum of potential evaporation minus rainfall exceeds a selected value. An average irrigation volume of 200 mm/year is applied over the 51 year climate record used in the simulation allowing for the irrigation volume to differ between years.

7.4 Groundwater Pumps

Eight groundwater pumps were added into the groundwater model of the Gardiner Creek case study area. The groundwater model indicated that pumps along the Moormbool fault (with higher aquifer hydraulic conductivity) could pump 33 ML/year without causing excessive drawdown in the local watertable. Outside the fault zone pumping rates of 16.7 ML/y were sustainable although this depended on the pump location. These pumping rates are ***NOT*** reliable as indicators of the bore yield possible in the Gardiner Creek catchment. Sustainable groundwater bore yield is highly dependent on the heterogeneous aquifer conditions in the immediate area of a bore and further field investigations (including drilling and pump tests) are required to provide a reliable estimate of sustainable yield.

In this investigation, 4 groundwater bores pumping at 33 ML/y and another 4 bores at 17 ML/y were located at different points in the model to provide the total 200 ML/y required to supply irrigation to 100 ha of irrigated grapes. The pumps were located within or alongside the areas marked as irrigated grapes in Figure 7-2. The land use 'irrigated grapes' was modelled so that it did not replace any areas currently modelled as native trees/shrubs.

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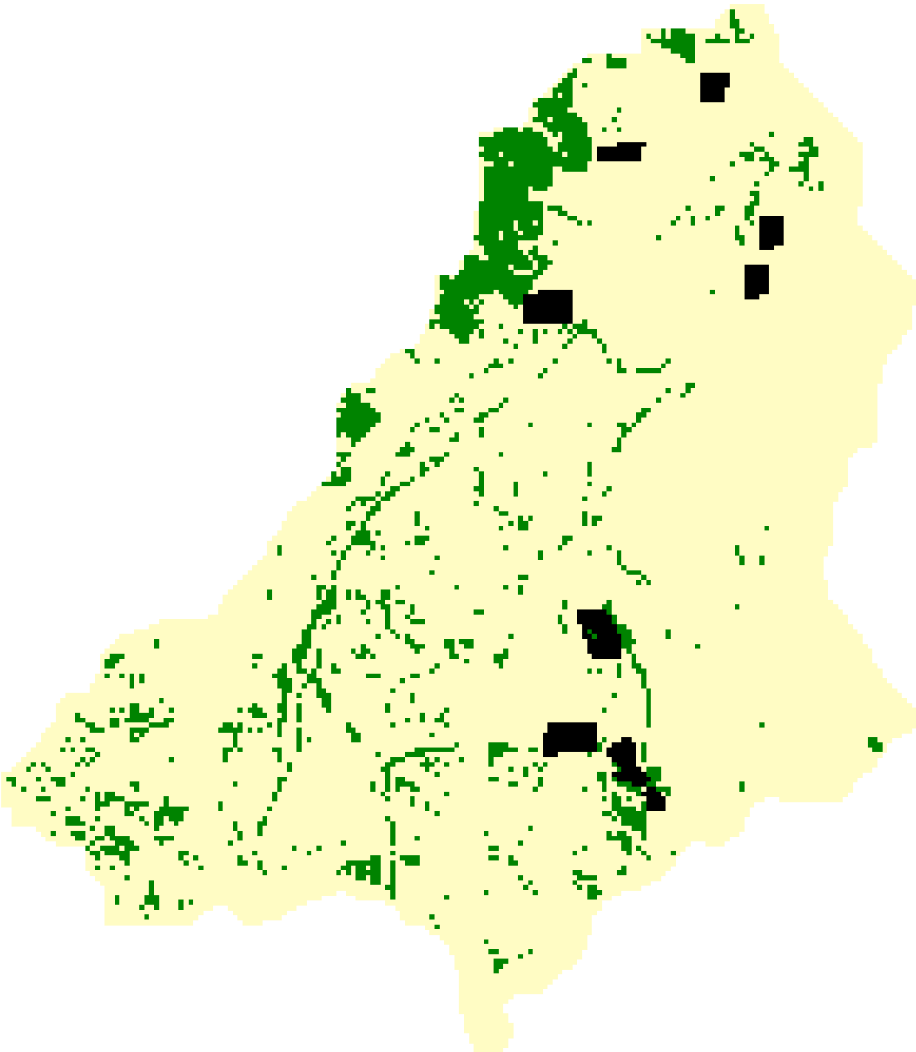
▪ **Figure 7-2 Gardiner Creek land uses: irrigated grapes (black), current trees (dark green), other land uses (light yellow). Groundwater pumps are located with or immediately beside the irrigated areas.**



7.5 Summary of results

The component model of the soil profile

Table 7.1 lists selected outputs from three land use scenarios in the Gardiner Creek case study area including the scenario with 100 ha of irrigated vines.

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Table 7.1 Gardiner Creek: summary of stream flow and salt load for three scenarios of land use.

	Total Catchment Area (hectares)	Area of Trees (hectares)	Area of Irrigated Vines (hectares)	Total Flow from Gardiner Creek (mm/year)	Total Salt Load from Gardiner Creek (t/year)
Current Land Use	5119	496	0	79.20	2714
30 % Tree Cover (from SWG Part 1)	5119	1552	0	70.25	2183
Current Land Use plus 100 ha irrigated vines	5119	496	100	77.62	2613

The salt load benefit of irrigated vines is calculated to be 1.01 t/y per hectare of irrigated vines (using the data in Table 7.1). The salt load benefit of planting trees is calculated to be 0.50 t/y per hectare of trees (using the data in rows 1 and 2 of Table 7.1). An alternative approach to estimating the salt load benefit of planting trees uses Equation [5.1] and the value of $K = 1.02$ (Table 5.1) giving a figure of 0.587 t/y per hectare of trees. Therefore the salt load benefit of irrigated grapes is up to twice as effective as planting trees on a land area basis.

A rough cost estimate for the installation of groundwater pumps is $20,000 per pump. In contrast, planting or seeding areas to native shrubs/trees is estimated at $1000/ha. Thus in the modelled example the development of 200 ha of native trees would cost $200,000 and the installation of 8 groundwater pumps to irrigate 100 ha would cost $160,000. These are costs that may be subsidised by the Goulburn Broken Catchment Management Authority to achieve a similar salt load benefit.

In conclusion, this modelling work indicates that the development of small-scale groundwater pumping schemes should be further evaluated as an effective approach to reducing salt load. The intensification of production that results from such developments has other additional benefits that are not considered here.

8. Conclusions

The primary aim of Part 2 of the South West Goulburn project has been to identify areas where afforestation with native vegetation/trees will bring about an effective long-term reduction in salt load export. The results that meet this aim are presented above in Section 5, and this work is supported by the earlier sections in the report.

Improvements in the representation of streams in the MCS model produce a more realistic watertable surface around stream beds, and this contributes to an improved catchment water balance. It also reduces the difference in effects of trees planted alongside streams and trees planted away from streams (the large differences noted in Part 1 between the 45 % trees and 45 % trees – relocation scenarios are now reduced).

Differences in the estimates of salt load carried in surface runoff were reduced a little in the new model developments (estimates are from stream gauge records and from the MCS model). An approach to improving the agreement of salt load estimates would be to undertake a more detailed calibration of the model for a small number of storm events (perhaps 10).

The approach developed to identify locations suited to afforestation across the South West Goulburn that would produce long term salt load reductions used the following spatial data sets:

- existing tree cover;
- depth to watertable (DWT);
- topographic characteristics (topographic wetness index, TWI); and
- characteristics of groundwater recharge.

Many combinations of rules for using the spatial data sets were considered.

Stream flow and salt load are both reasonably well characterised by a linear relationship with tree cover in the case study areas (Figure 5-1 to Figure 5-4). A perfectly linear relationship would suggest that the effects of trees are independent of location in the catchment. However some variation between tree cover scenarios is noted indicating that, for the same percentage tree cover, different approaches to locating trees in a catchment may have different effects on salt load. Differences between the two case study areas were also observed.

The effect of different tree cover scenarios at the scale of the South West Goulburn are estimated using the approximate linear relationships between stream flow and tree cover and between salt load and tree cover. The REALM model was used to estimate the effects at the 'end of valley' of four scenarios of tree cover across the SWG.

The results allow the following key conclusions to be drawn.

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Key Conclusions for the Methodology:

- Proposals for land use change in the South West Goulburn can be examined using the MCS and REALM models. These models allow the salt load reduction to be estimated for the Goulburn River at the end-of-valley.
- The conclusions reached are considered to be robust and are not strongly dependent on any particular input parameter to the MCS model.

Key Conclusions for Catchment Management:

- An increase in tree cover is effective in reducing the salt load exported from the South West Goulburn. (Other deep rooted vegetation with similar water use characteristics to the modelled trees would also be as effective.)
- The increased water use by trees (compared to pasture) is effective in reducing salt load regardless of where the trees are located. **It is likely to be more effective increasing percentage tree cover than siting a lower tree cover in the best locations.**
- Optimising the spatial distribution of trees can provide small additional gains in salt load reduction for a given area of trees. These additional gains are secondary to the primary advantage gained from percentage tree cover.
- Small blocks of trees in areas with high watertables are unlikely to be effective in long term salt load reduction. However, local groundwater salinity and groundwater drainage conditions will influence this result (e.g. use of low salinity groundwater by trees may be effective in some settings).
- Significant reductions in Murray River salinity could be achieved by large scale tree planting. The current area of trees in the South West Goulburn (approximately 24 %) would need to be approximately doubled to achieve a salinity reduction at Morgan of 3 EC. In addition, tree planting also reduces the salinity of irrigation water diverted from Goulburn Weir to the Shepparton East Main Channel and the Waranga West Main Channel.
- Specifically, a 50 % tree cover in the South West Goulburn would reduce the salt load into Goulburn Weir by 13.0 % and this would be associated with a 4.9 % reduction in flow (see Figure 5-6 and Figure 5-7). These reductions quantify the effect of increased cover on downstream irrigators. The reductions would be 12.4 % and 18.8 % for flow and salt load in the Goulburn River at Murchison (this quantifies the effects on the Murray River).
- Application of the model indicates that the development of small-scale groundwater pumping schemes should be further evaluated as an effective approach to reducing salt load. The salt load benefit of establishing an area of irrigated grapes is found to be up to twice as effective in reducing salt load as planting an equally-sized area to trees.

- A preliminary economic analysis using typical incentives available through the Goulburn Broken CMAs program revealed that, where suitable groundwater reserves could be located, groundwater based irrigation enterprises would provide a more cost effective return on public investment for salt load reduction than revegetation.
- The tree cover scenarios developed in this report provide input to more comprehensive evaluations of land management options that would also consider economic and social influences on land managers. The scenarios are best considered at the scale of the South West Goulburn, however the rules/principles used to locate trees are also useful at the paddock scale. Thus, paddocks where the watertable lies at a depth less than 5 m are unlikely to be effective in long-term salt load reduction.

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Appendix A Review of Literature Characterising Trees

A.1 The distribution of tree roots

Any discussion of tree water use and water use efficiency must include consideration of root systems. The distribution of tree roots in soil depend on a number of factors (e.g. tree species, the size and age of the tree, soil type, availability of water and density) – roots grow more easily through low density soils, and they grow preferentially where conditions are good (e.g. more available of water).

The most relevant study may be the studies of the plantation at Kyabram, in the Shepparton Irrigation Region. Silberstein et al. (1999) found that active roots were at least 10 m below the surface.

Plants in drier environments usually have deeper root systems. A survey of global patterns of root distribution was given by Jackson et al. (1996), and Canadell et. Al. (1996) collected known information on rooting depth. On a global average, desert vegetation reaches a maximum rooting depth of 13.4 m, with 37 % of the total root biomass below 0.3 m soil depth, while temperate forests have a maximum rooting depth of 3.7 m, with 35 % of the root biomass below the 0.3 m soil depth. The root systems of temperate grasses reach a maximum depth of only 2.4 m, and have only 17 % of the total root biomass below 0.3 m.

Adar et al. (1995) demonstrated the extraction of groundwater by a tamarisk tree in arid sand dunes from a depth of more than 15 m, and De Vries et al. (2000) detected extraction of water deep-rooting acacia species from depths exceeding 50 m in the Kalahari desert.

Kimber (1974) reported that a well-developed root system of Jarrah tree penetrates down to the watertable which was from 15 to 20 m below surface in south-western Australia. He found that jarrah has a dense lateral root system confined to the gravel zone in the top 0.9 m above the massive laterite layer. Beneath this a well-developed sinker root system penetrates down to the watertable, and develops into a secondary fine root system in the clay above the watertable, which may be from 15 m to 20 m below the soil surface.

A.2 Leaf area index

There are some studies regarding variation of leaf area index (LAI) of tree. Figure A.1 shows the variation in average plot LAI during a study conducted by Clifton and Miles (1998). Plot LAI values at site 1 increased by about one unit during the two years between the first and final measurement. There was an overall decrease in plot LAI at site 2 over the corresponding period.

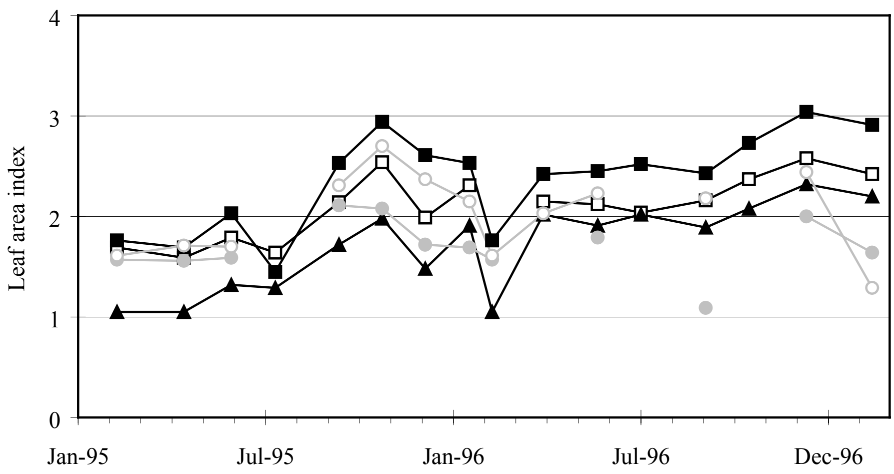
LAI of plot 2 was greater than that of other plots at site 1 throughout the study. This is consist with the trees on that plot being larger than those in other plots. The LAI of plot 1 was greater at the end of the study than that of plot 3, despite the trees being smaller. The difference in LAI between the two plots declined during the study. Differences in LAI between plots 4 and 5 were consistent with differences in other tree dimensions.

Fig. A.1 shows the influence of several factors on plot LAI. The spring-early summer growth flush in 1995 and 1996 resulted in LAI increasing by 0.5 - 1 unit on all plots. There was a major insect related defoliation event at both sites in February 1996, resulting in LAI falling by up to 1 unit. The trees quickly recovered from this event. Trees at site 2 suffered from quite severe foliage loss under the very dry late summer conditions experienced during February and March 1997.

Landsberg (1999) used 3-PG model to simulate LAI of Eucalyptus globulus over 20 years for varying climatic conditions: (1) low rainfall – 600 mm/y, (2) 900 mm/y and (3) 1200mm/y, associated with average monthly VPD varying from (1) 1.5 (summer) to 0.5 kPa (winter), (2) 1.2 to 5 kPa and (3) 0.9 to 5 kPa, respectively. Fig. A.2 shows time course of plantation LAI under these three climatic regimes. The curves reflect the increaseing dryness of the environment: top – high rainfall, low VPD; botom – low rainfall, higher average VPD.

A study by Pook et al. (1997) also showed that climate had considerable influence on the variation of leaf fall and fluctuations of forest LAI.

- **Figure A.1. Plot leaf area index (LAI) at Site 1 and Site 2, Warrenbayne between February 1995 and February 1997. Plot 1 (■), Plot 2 (□), Plot 3 (♦) - black line; Plot 4 (●), Plot 5 (○) - grey line.**



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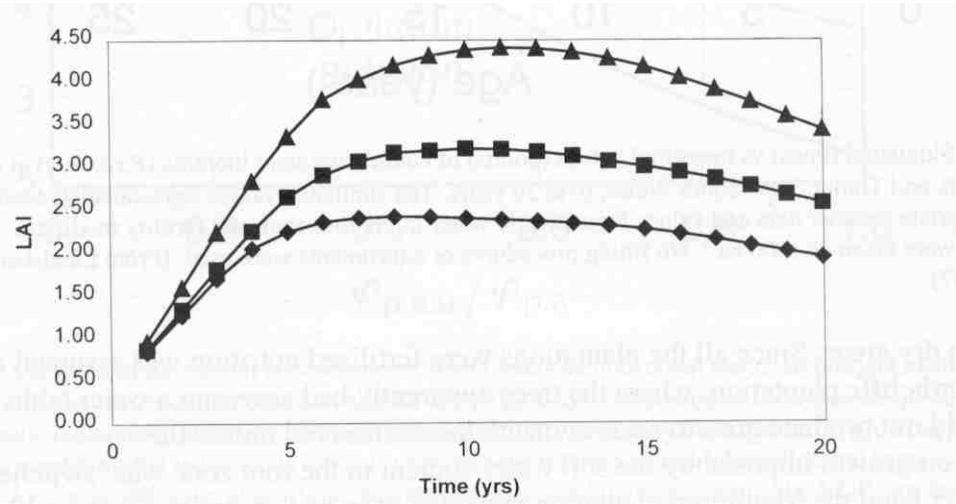
- **Figure A.2 Time course of plantation LAI under these three climatic regimes. The curves reflect the increaseing dryness of the environment: top – high rainfall, low VPD; botom – low rainfall, higher average VPD.**



Clifton et al. (1997) found that water uptake by 5-6 year old E.globulus and E.nitens (Shinning Gum) trees in a dense plantation near Colac exceeded annual rainfall (7-800 mm/yr). Linke et al. (1995) found that a dense six year old Pinus radiata plantation, established across a small catchment near Broadford, was able to lower watertable by 2m during the first six years after establishment.

A.3 The ridge top and the valley soils

Water uptake by the plantation will depend upon the rainfall received, the potential for trees to exploit it, and the capacity of the soil to store the rain until the trees can make use of it. Lorimer and Schoknecht (1987) described the typical soil types for the following landscape position and hydrogeological setting:

- Slope of a rocky ridge in sedimentary hill country – a shallow red gradational soil, with a free draining loamy A horizon and clay B horizon. The soil depth is normally less than 2 m.
- Break of slope position – a red gradational soil profile, with a free draining loamy A horizon, a light clay B horizon and underlain by a several metres of sandy clay colluvium. Total soil depth is normally greater than 4 m.
- Alluvial or riverine plain environments – a deep red duplex soil, with a loamy A horizon, clay B horizon and underlain by silt loam alluvium to 4 m depth.

In Victoria, tree have been planted to reduce groundwater recharge in the fractured rock uplands of the Great Dividing Range over several decades. Trees have been planted in shallow permeable soils in the upper parts of the landscape and have been expected to extend their roots and crown across the planted area and thus reduce or eliminate groundwater recharge. In general, these plantations have grown slowly due to the limited water and nutrient availability and the use of indigenous species. Clifton and Dyson (1997) found that at the sub-catchment scale, the impact of such plantations on watertables will be limited by the area planted and the relative contributions to catchment recharge of the planted and unplanted areas. However, in a modelling-based assessment of the hydrologic effects of seven vegetation systems in Victoria, Clifton and McGregor (2000) concluded that the most effective systems were tree plantations and native vegetation systems. These systems were found to be able to evaporate a relatively large proportion of annual rainfall and lost relatively little water as deep drainage. The study also concluded that warm and cool season perennial pastures (lucerne and phalaris respectively) and phase farming were also effective, but less effective than plantations and native vegetation systems in containing groundwater recharge.

Dryland salinity often relates to the movement of groundwater from positions high in the landscape to positions lower in the landscape. The process provides an opportunity for strategically placed plantations to intercept the groundwater in transit provided the groundwater is not too saline (Dyson 1992). This idea suggests that tree plantations not only reduce accessions of rainfall to the watertable, but may also act as 'pumps' to draw on groundwater and create a groundwater depression in the aquifer that allows water from the surrounding area to drain. However, in many cases the groundwaters have a salinity that is not conducive to plant health. The unsustainability of tree growth at saline sites without sufficient periodic leaching of salts, which otherwise accumulate in the root zone, has been modelled and documented (Thorburn, Walker & Jolley 1995; Morris 1999; Silberstein 1999), and well witnessed in some areas.

A.4 Appendix A - References

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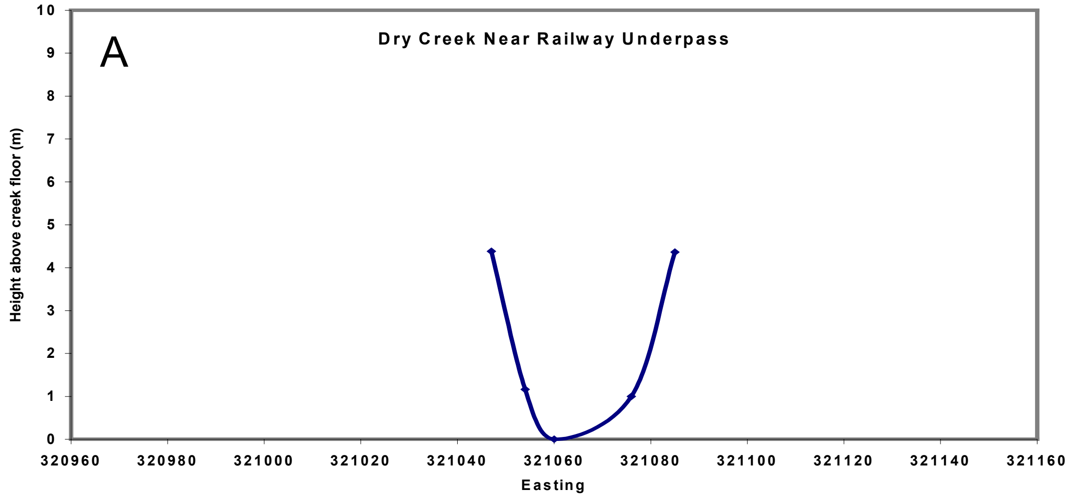
Appendix B Stream Bed Cross Sections

The data for the following cross-sections was recorded by DPI Broadford.

- **Figure B.1 Surveyed cross sections of Dry Creek.**



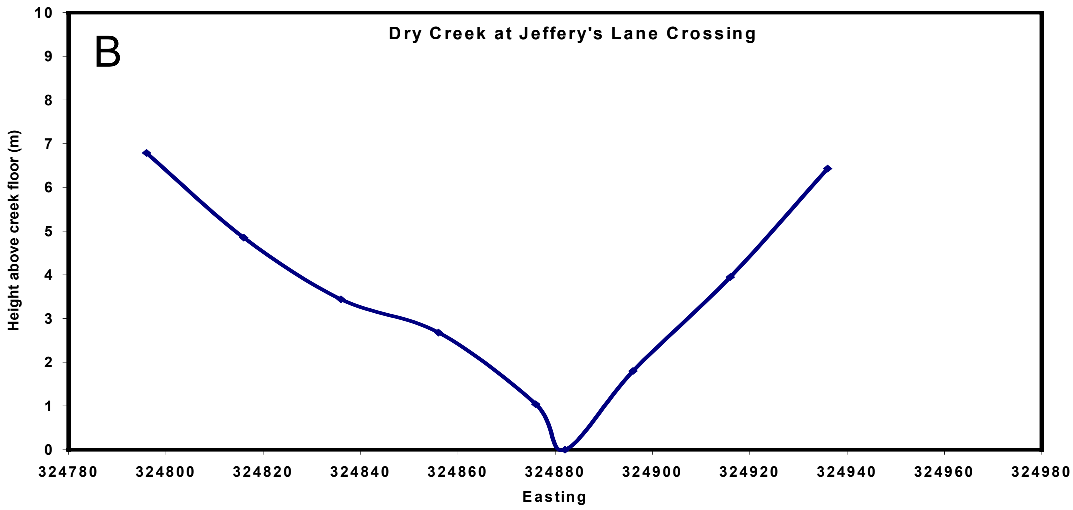
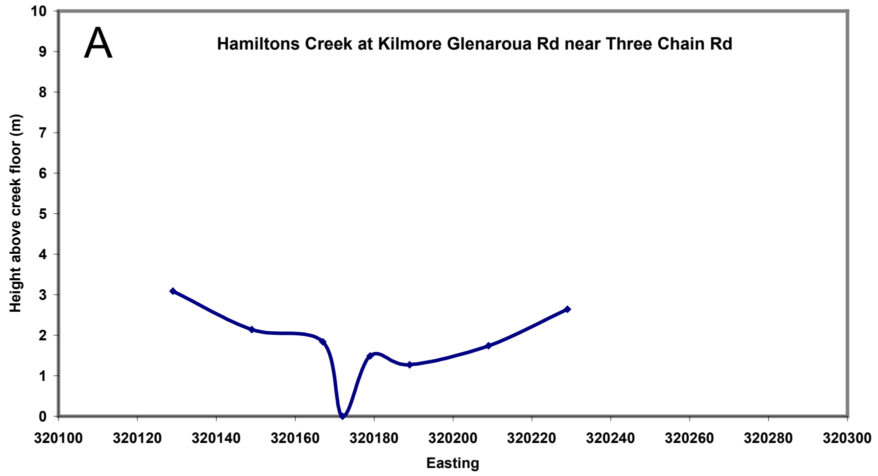
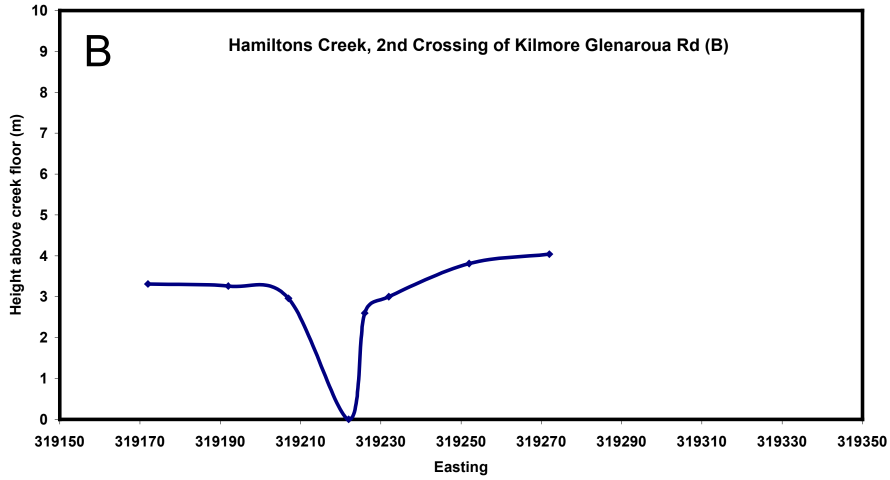
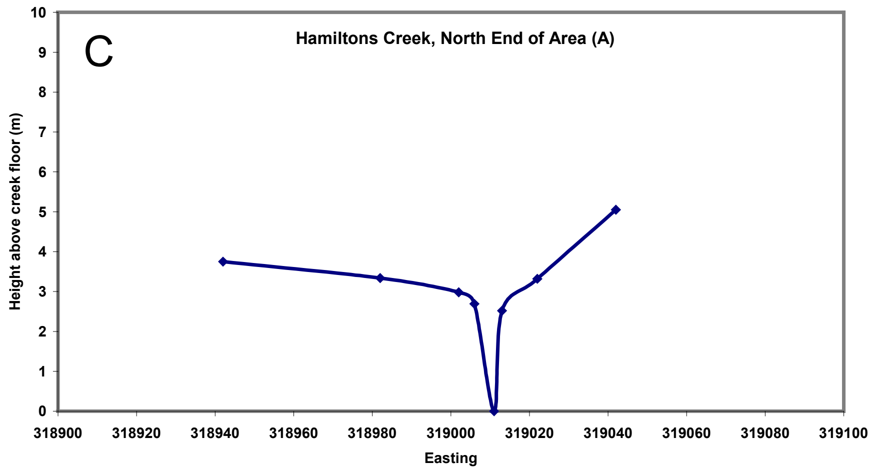


Figure B.2 Surveyed cross sections Hamilton Creek







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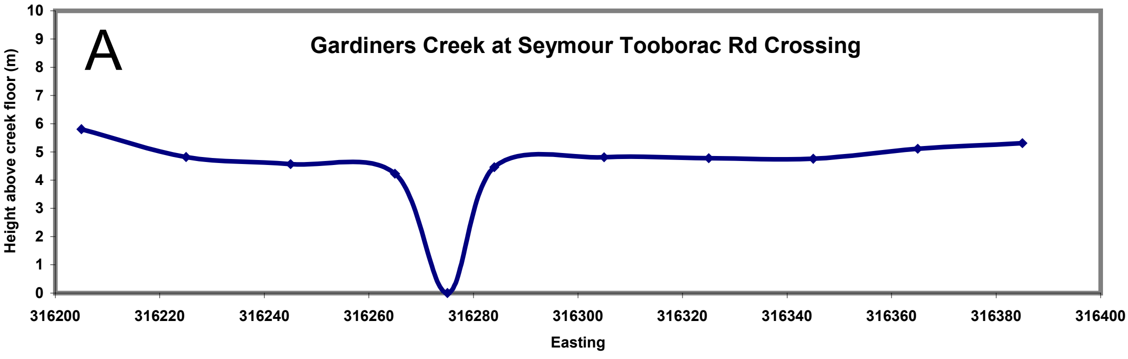
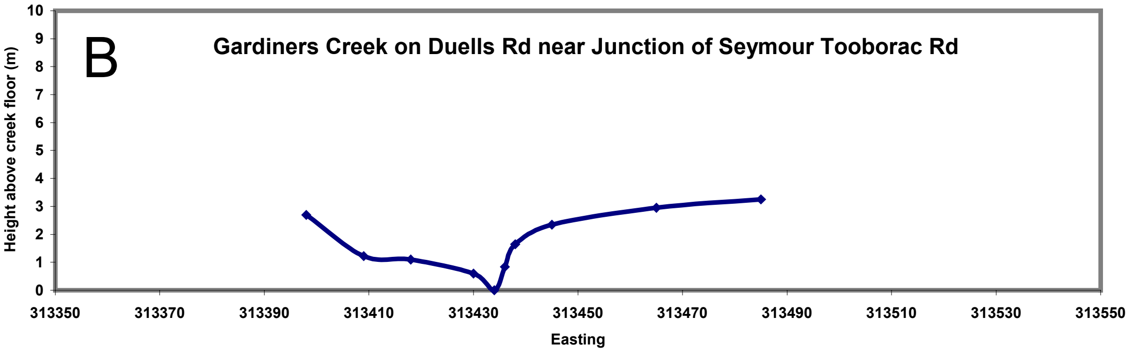
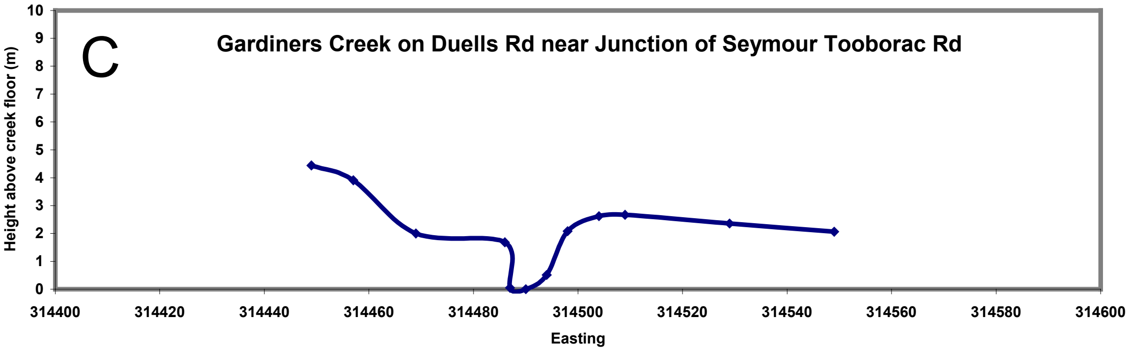
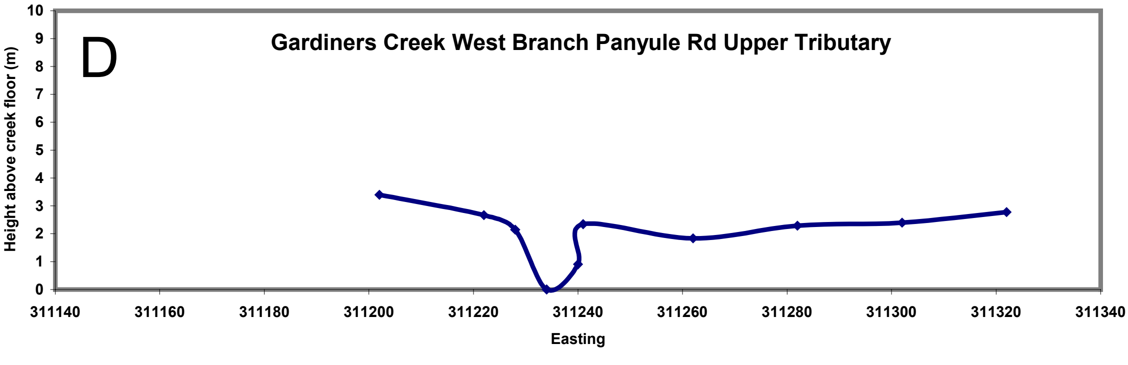
- **Figure B.3 Surveyed cross sections Gardiner Creek**





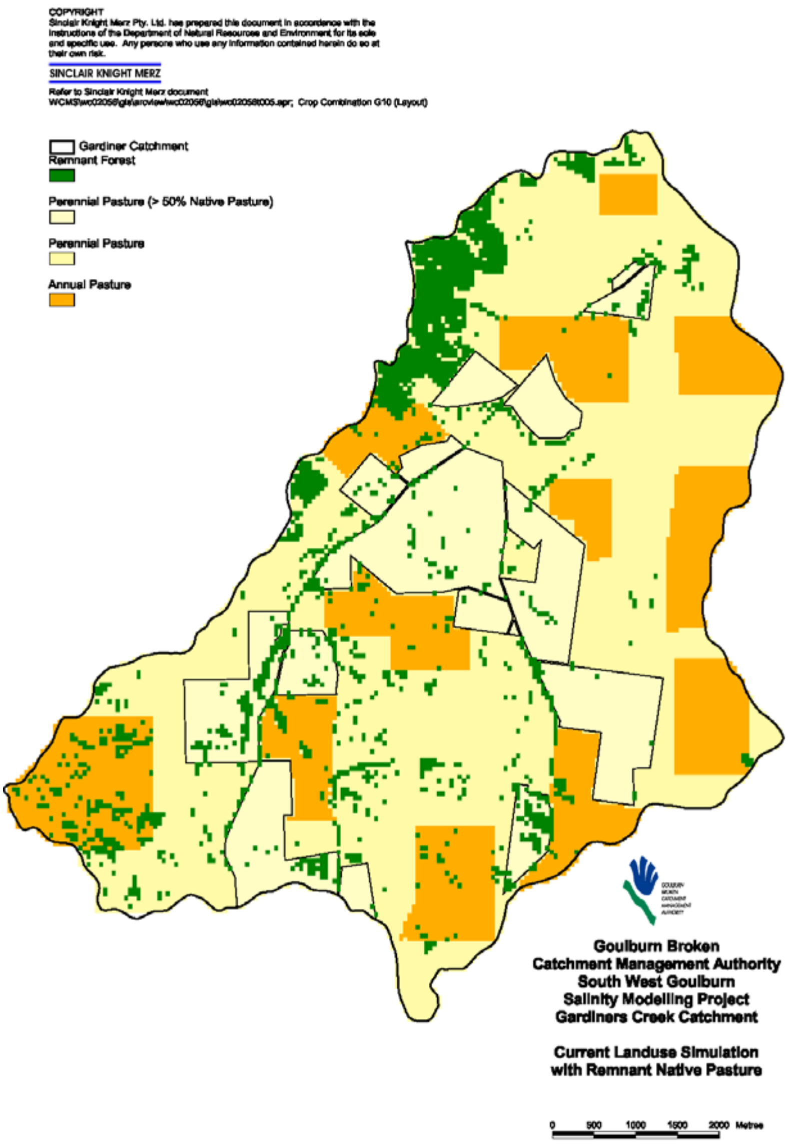




Appendix C Maps of Native Vegetation/Tree Cover in the Case Study Areas

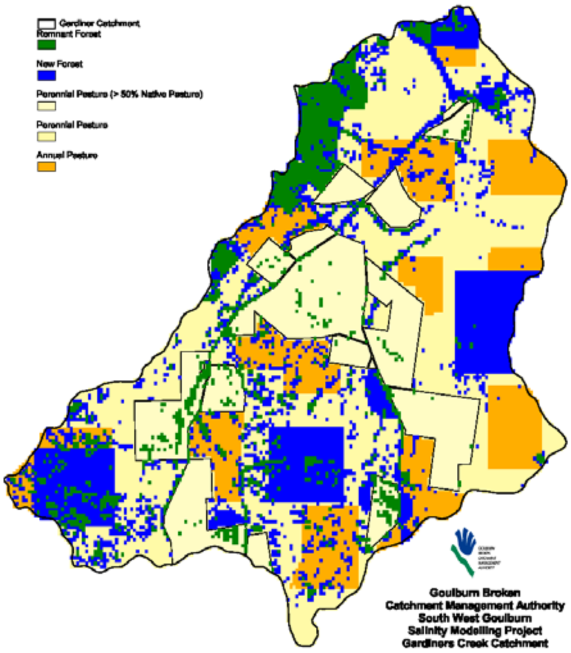
C.1 Gardiner Creek Case Study Area

■ **Figure C.1 Gardiner Creek: Current Land Use as interpreted in Part 1 of the project. Tree cover shown in green.**

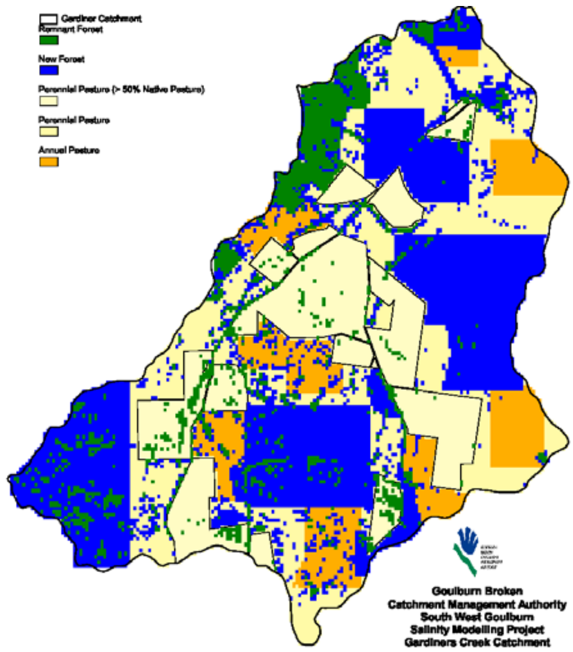


▪ **Figure C.2 Gardiner Creek: Scenarios of tree cover developed in Part 1 of the project. Tree cover shown in blue and green. (a) 30 % tree cover; (b) 45 % tree cover; (c) 60 % tree cover; (d) 45 % tree cover – relocation.**

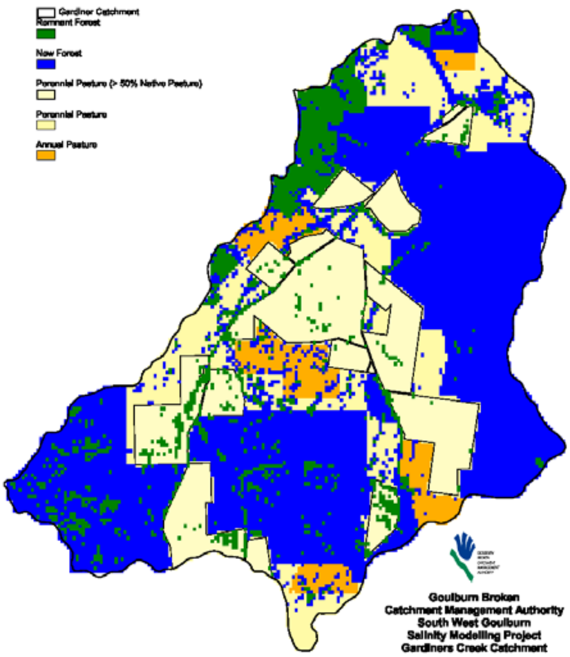
(a)



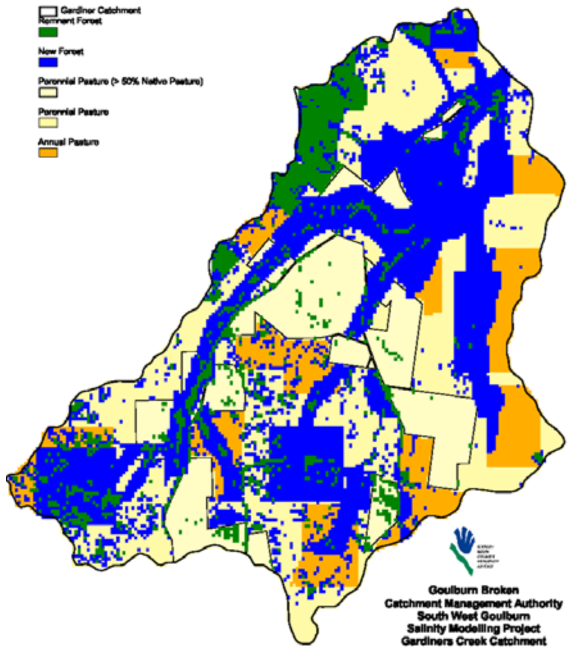
(b)



(c)



(d)



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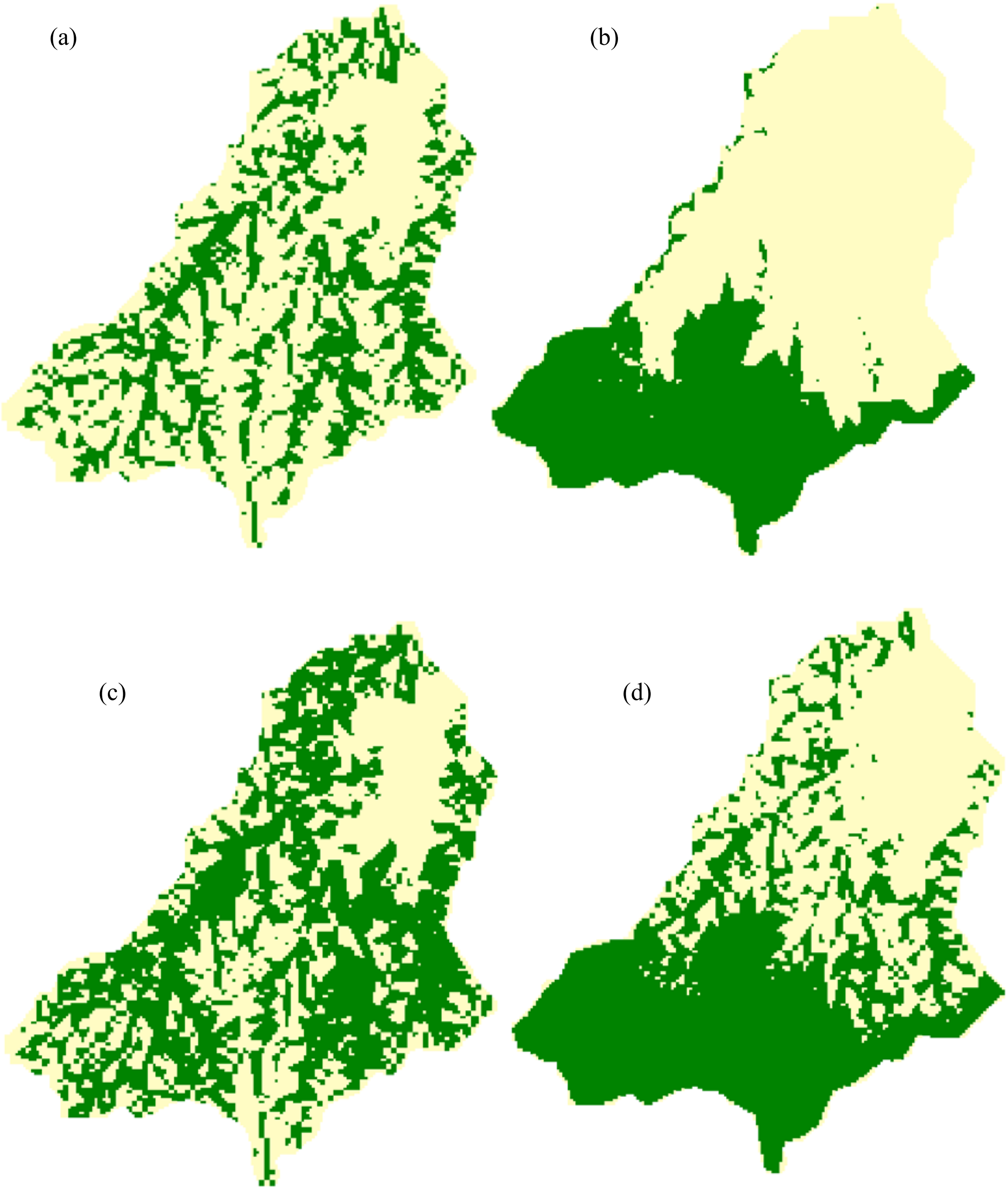
- **Figure C.3 Gardiner Creek: Scenarios of tree cover used in Part 2 of the project. Tree cover is shown in green. The scenarios are as follows: (a) 34 % Tree Cover TWI34, (b) 38 % Tree Cover DWT38, (c) 53 % Tree Cover TWI53, (d) 54 % Tree Cover DWT54.**



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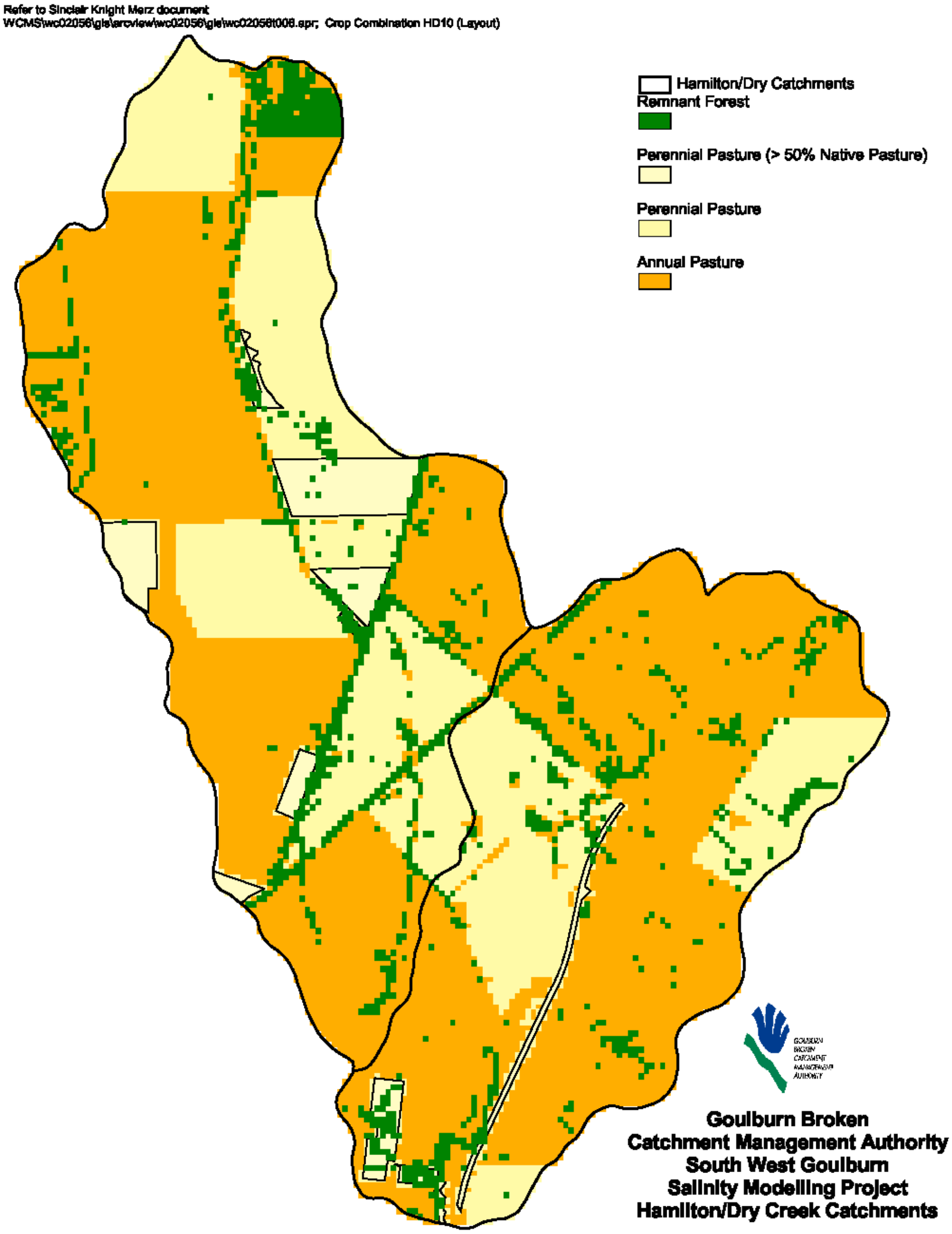
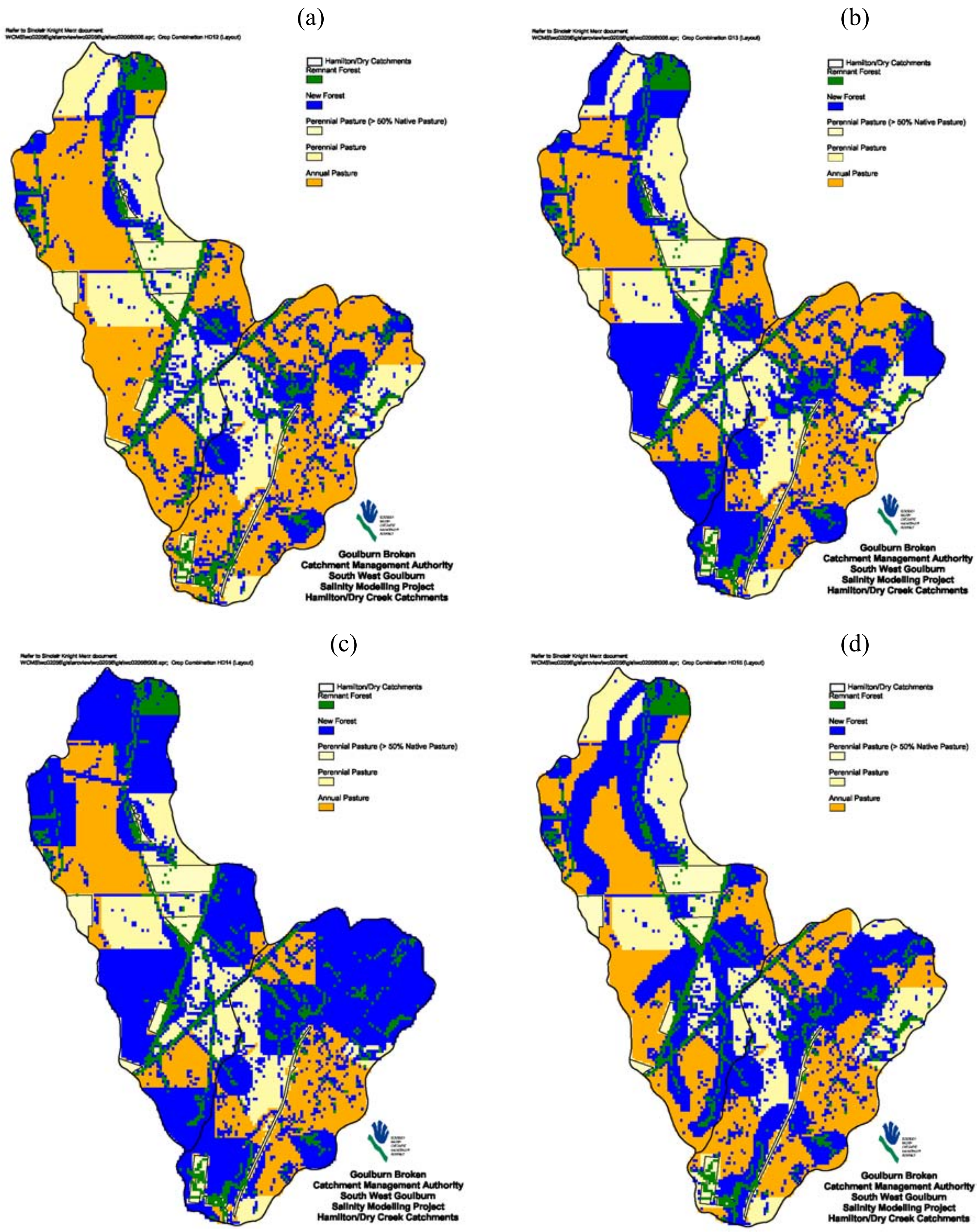
C.2 Hamilton/Dry Creek Case Study Area

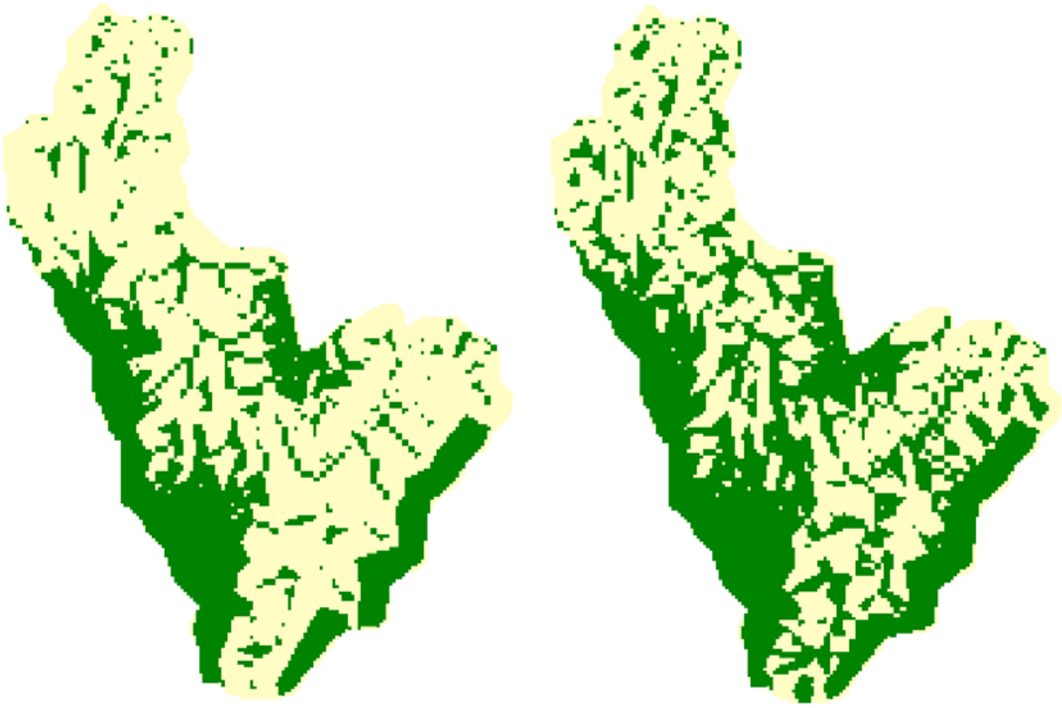
- **Figure C-4. Hamilton/Dry Creek: Current Land Use as interpreted in Part 1 of the project. Tree cover shown in green.**



- **Figure C-5. Hamilton/Dry Creek: Scenarios of tree cover developed in Part 1 of the project. Tree cover shown in blue and green. (a) 30 % tree cover; (b) 45 % tree cover; (c) 60 % tree cover; (d) 45 % tree cover – relocation**



▪ **Figure C-6. Hamilton/Dry Creek: Scenarios of tree cover used in Part 2 of the project. Tree cover is shown in green. The scenarios are as follows: (a) 34 % Tree Cover TWI34, (b) 48 % Tree Cover TWI48.**



Appendix D South West Goulburn Tree Cover Scenarios

This Appendix presents figures of the current tree cover and four scenarios of proposed tree cover described in the text. The scenarios were developed by Mark Cotter (DPI Benalla). The rules used to identify tree areas in the scenarios were applied in ArcView and as a result there are some small areas that are shown in Figure D-1 that are not shown as tree areas in Figures D-2 to D-5. These differences would be eliminated if a more detailed analysis was undertaken in ArcInfo. The difference was only found to be significant for the Major Creek subcatchment under Scenarios 2 to 4. In Major Creek the tree area in the scenarios was arbitrarily increased so that it would not be less than the current tree area for any scenario.

Note that inputs to the REALM model only considered tree cover within the 8 subcatchments in the South West Goulburn that contribute to flow in the Goulburn River at Goulburn Weir. Some areas shown are part of the South West Goulburn region as used by the Goulburn Broken CMA, but not actually part of the Goulburn catchment.

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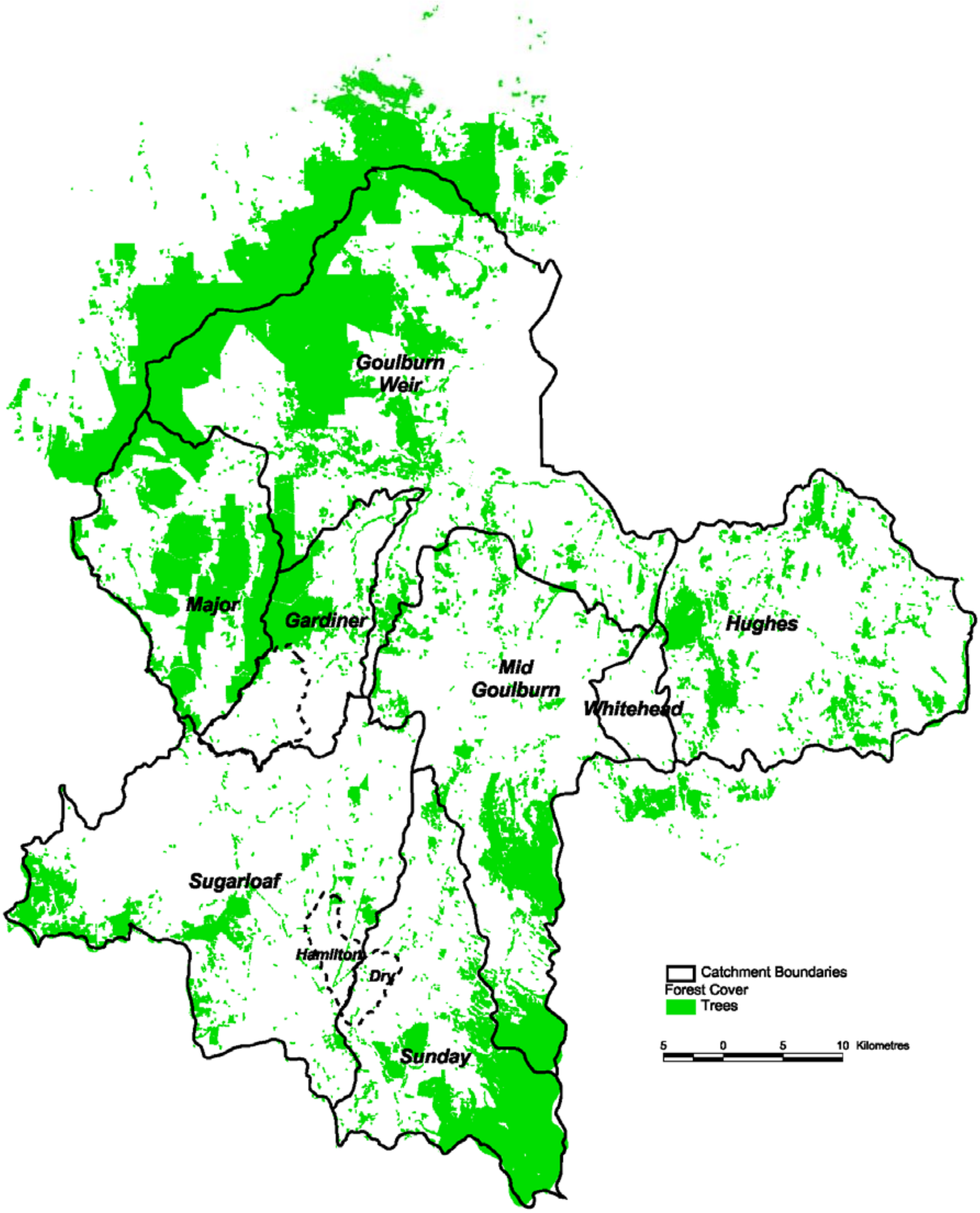
- **Figure D-1 Existing Tree Cover in the South West Goulburn. Areas with native vegetation/trees are shown in green. Outlines are drawn for the 8 subcatchments used by the REALM model and for the two case study areas (dotted lines).**



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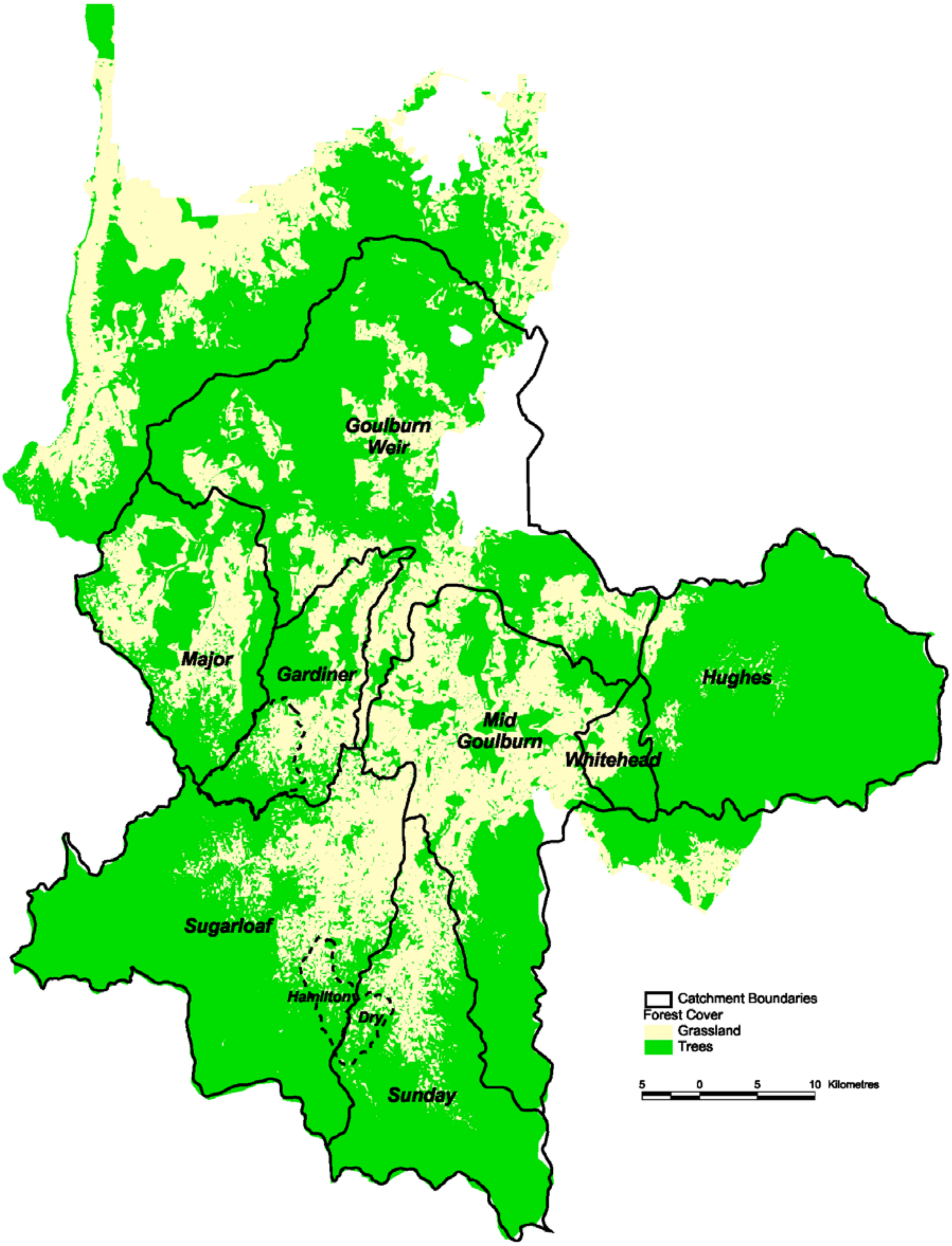
▪ **Figure D-2 Scenario 1: Proposed Tree Cover in the South West Goulburn. Areas with native vegetation/trees are shown in green. Outlines are drawn for the 8 subcatchments used by the REALM model and for the two case study areas (dotted lines).**



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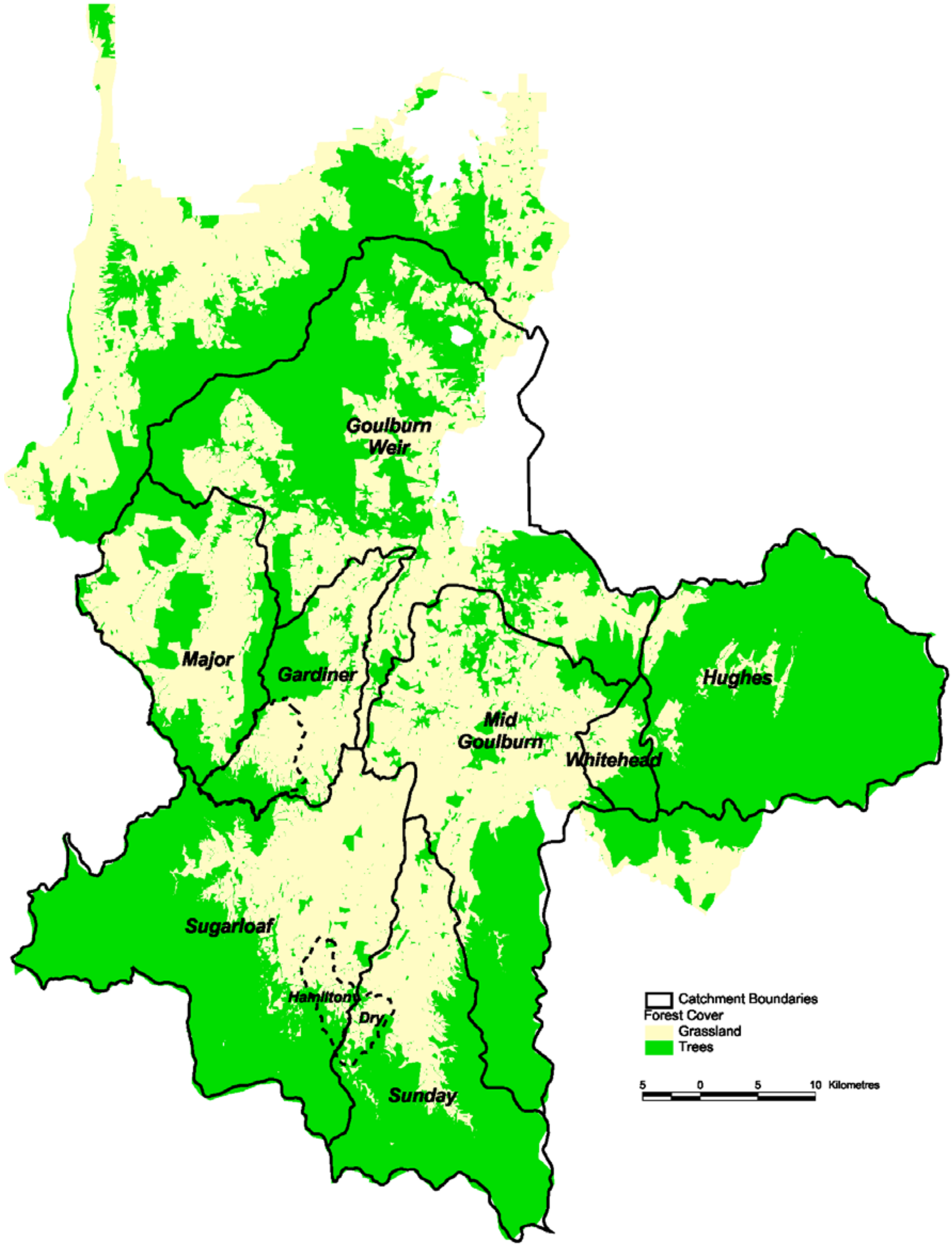
■ **Figure D-3 Scenario 2: Proposed Tree Cover in the South West Goulburn. Areas with native vegetation/trees are shown in green. Outlines are drawn for the 8 subcatchments used by the REALM model and for the two case study areas (dotted lines).**



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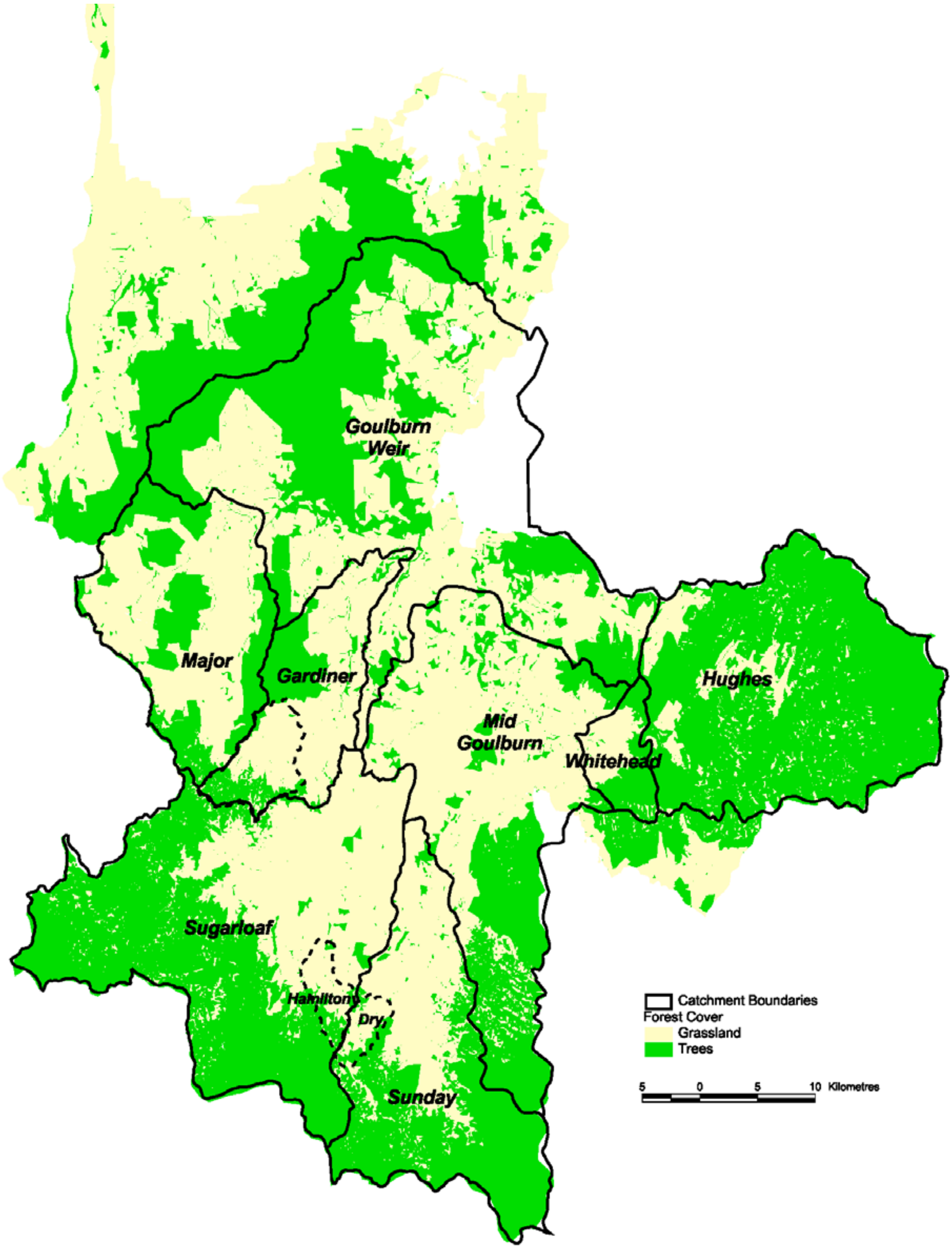
■ **Figure D-4 Scenario 3: Proposed Tree Cover in the South West Goulburn. Areas with native vegetation/trees are shown in green. Outlines are drawn for the 8 subcatchments used by the REALM model and for the two case study areas (dotted lines).**



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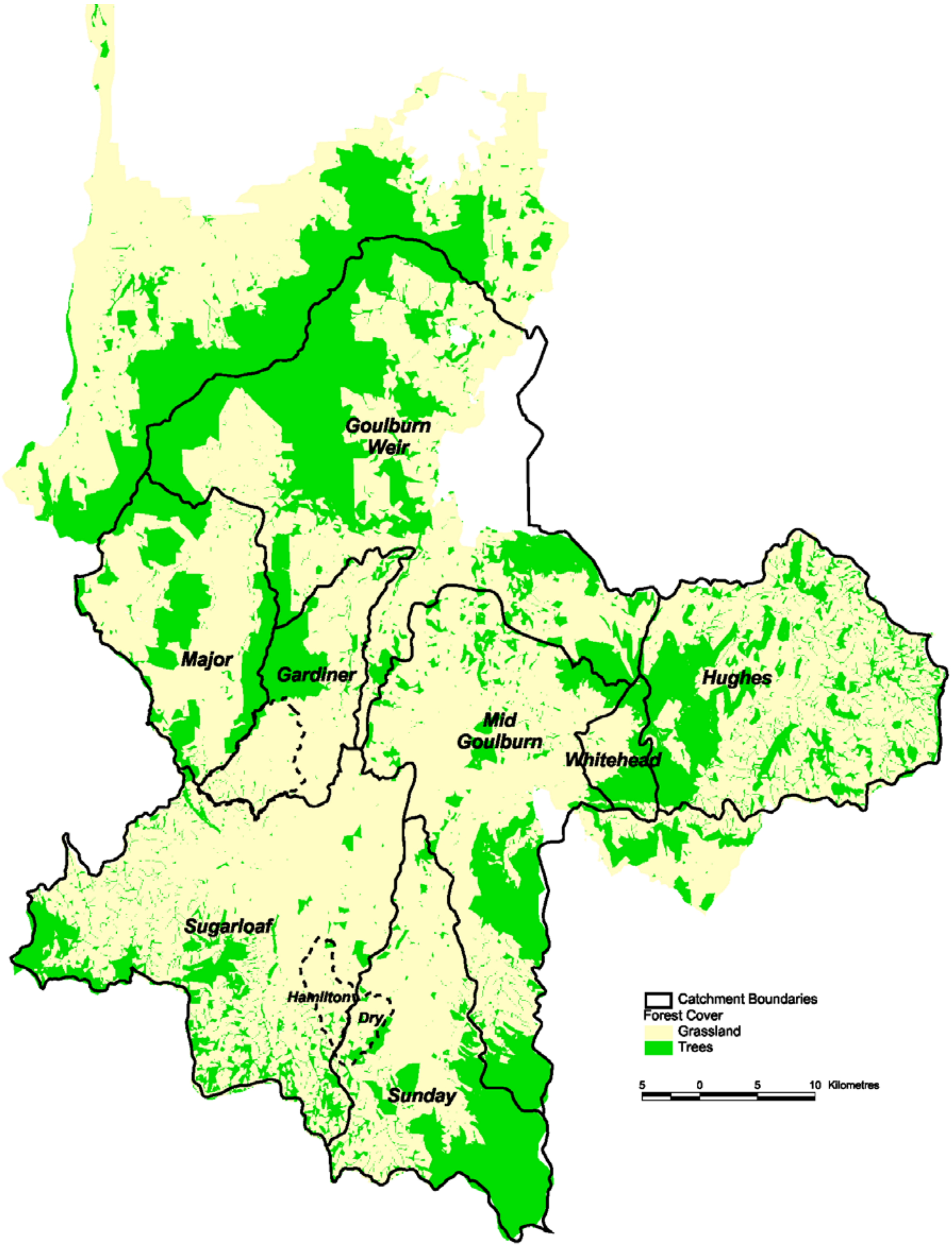
- **Figure D-5 Scenario 4: Proposed Tree Cover in the South West Goulburn. Areas with native vegetation/trees are shown in green. Outlines are drawn for the 8 subcatchments used by the REALM model and for the two case study areas (dotted lines).**



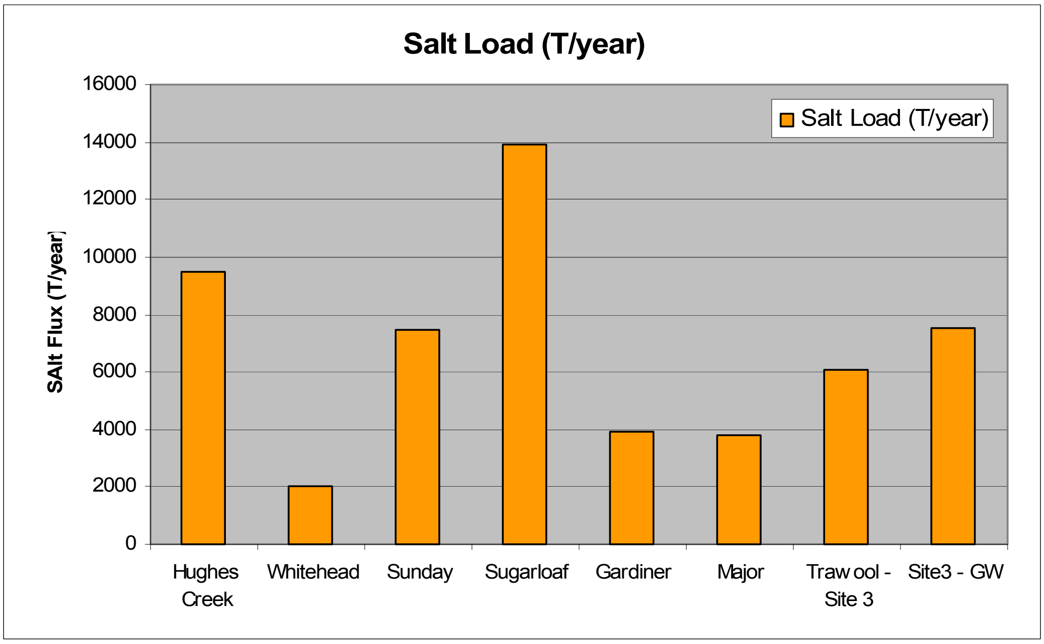
Appendix E REALM Subcatchment Water and Salt Fluxes

This appendix provides additional information about flow and salt load from subcatchments used in the REALM model of the Goulburn River. These fluxes were adjusted in order to model the effects of the tree cover scenarios on the flow and salt load out of the South West Goulburn.

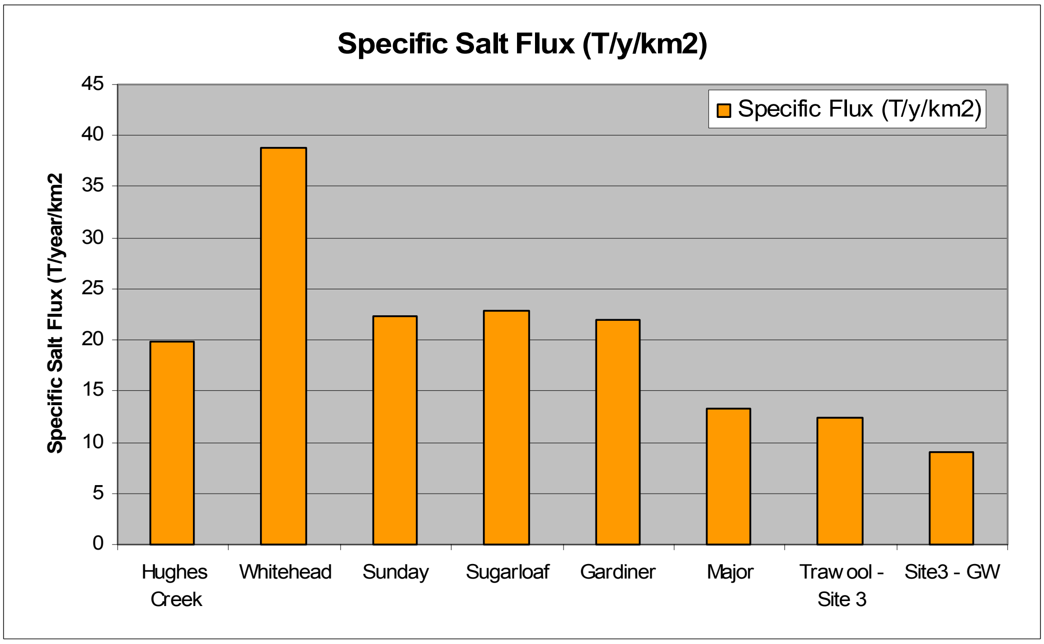
Table E.1 Indication of the presence of stream gauges used to quantify flow and salinity from subcatchments in the REALM model.

	REALM Sub Catchment	REALM Flow Gauge	REALM Salinity Gauge
Gauged	Hughes	No	Yes
	Whitehead	No	Yes
	Sunday	Yes	Yes
	Sugarloaf	Yes	Yes
	Gardiner	No	Yes
	Major	No	Yes
Ungauged: used for flow only	Trawool to Site3 (called 'Mid Goulburn' in this report)	No	
Ungauged: used for flow only	Site3 to Goulburn Weir (called 'Goulburn Weir' in this report)	No	
Ungauged: combined area of above 2, EC only	GW Ungauged		No

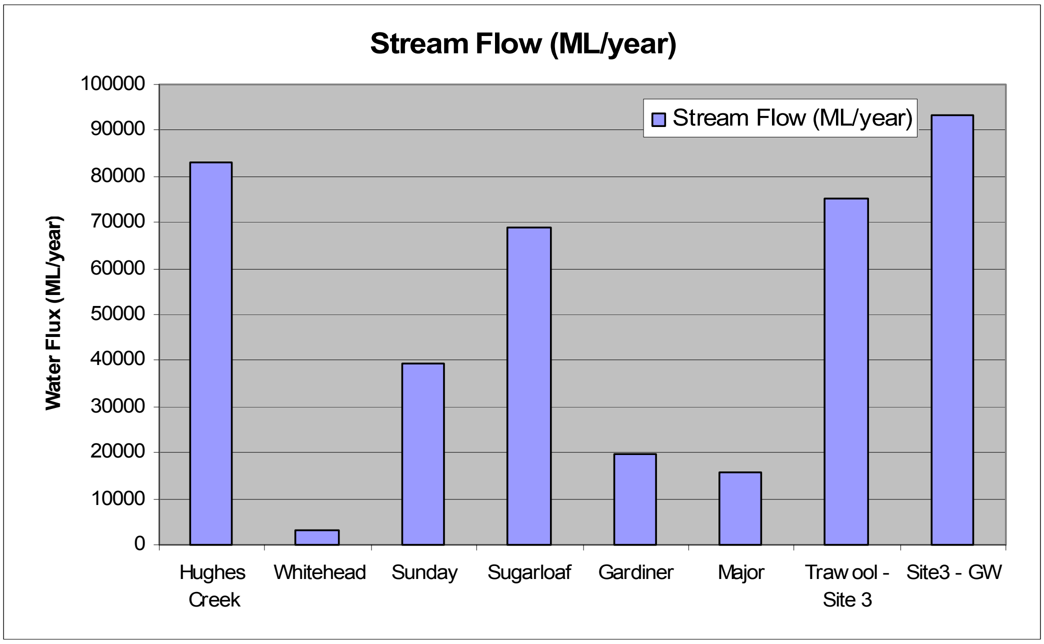
▪ **Figure E.1 Salt Load in Study Catchments (Tonnes/year)**



▪ **Figure E.2 Specific Salt Flux in Study Catchments (Tonnes/year/Kilometre squared)**



- **Figure E.3 Stream Flow in Study Catchments (Megalitres/year).**



- **Figure E.4 Specific Flux in Study Catchments (Megalitres/year/Kilometre squared)**