Government of **Western Australia**
Department of **Water**

Salinity situation statement
Tweed River and Gnowergerup Brook

Water resource technical series

Report no. WRT 41
October 2009

Looking after all our water needs

Salinity situation statement: Tweed River and Gnowergerup Brook

by

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Department of Water

Water Resource Technical series

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Cover photo: Gnowergerup Brook at Jayes Road gauging station
Photographer: Graeme Blake

Contents

Appendices

Figures

Tables

Preface

The Tweed River and Gnowergerup Brook, tributaries of the Blackwood River, are currently affected by elevated levels of salinity. The Blackwood Basin Group have nominated the catchments of these two streams as having the potential, with the right management, to be recovered from their salt-affected status.

To plan this salinity recovery, the Blackwood Basin Group intends to use a process similar to the Department of Water's 'Water Resource Recovery approach'.

An important component is to collate and analyse stream gauging records to describe the past and current salinities and flows in the rivers and their catchments and to model the hydrological (salinity and flow) outcomes of some management scenarios. The results are published in a 'Salinity Situation Statement' report.

Summary

The salinities of the Tweed River and Gnowergerup Brook are not expected to increase significantly provided that there is no further clearing.

Although the Tweed River and Gnowergerup Brook catchments occupy only 3% of the Blackwood Basin area, these two catchments contribute 11% of the Blackwood River's annual salt load and 4% of its annual flow. Current (1999–2006) flow-weighted salinity and average streamflow for Gnowergerup Brook at Jayes Road are 5381 mg/L and 15.9 GL respectively.

The Blackwood River is the largest waterway by flow in the south-west of Western Australia and has gradually become saline over time due to widespread vegetation clearing. The river exports about one million tonnes of salt each year and the water is too salty for horticulture.

The Blackwood Basin Group (BBG), a community-based organisation that coordinates environmental management within the Blackwood River catchment, is intent on reducing stream salinity in the catchment.

The project to develop two water quality recovery plans for stream salinity in the Blackwood was commissioned by the South West Catchments Council (SWCC) as part of their regional natural resource management (NRM) investment plan for 2005–06. Of the eleven identified catchments in the middle Blackwood target area, the Tweed River and Gnowergerup Brook catchments were selected as key areas in need of salinity recovery given their high relative salt contributions to the Blackwood River. The benefits the BBG seeks in lowering catchment salinity levels relate to improving the ecological function and health of the Blackwood River.

To achieve their aims, the BBG needs to know the extent of the salinity problem now, what may happen in the future, what can be done to reduce or reverse the problem and the likely effectiveness of any proposed actions or management scenarios. The Land Use Change Integrated Catchment (LUCICAT) model was used by the Department of Water to project the likely salinity and streamflow effects of selected land-management scenarios in these catchments in the years 2030 and 2060. This will assist decision making by the BBG and landholders.

At this stage modelling does not account for the likely climate changes. Assumptions and estimates used in modelling mean that results are estimates, but the relative results for the various management options may help decision making by the BBG.

Five management scenarios were modelled and analysed in depth:

1. Base case — Leave the catchments in their current state ('do nothing'). The total cleared area in 2007 was 362 km^2.

2. Upland trees — Replant 82% of the cleared areas with trees, focusing on the upper catchment.

3. Strategic trees — In areas of high salt contribution replant 59% of the cleared areas with trees.

4. Strategic trees and perennials – In areas of high salt contribution, replant 59% of the cleared areas with trees and the remaining cleared areas with deep-rooted perennial pastures (3.5 m rooting depth).
5. All cleared — Clear all the remaining native vegetation.

Scenario 4: strategically located trees in areas of lower elevation with perennial pastures in the remaining cleared areas is the most hydrologically effective to lower stream salinity. Projected salinities for 2030 were 641 mg/L total dissolved solids (TDS) for the Tweed River and 1039 mg/L for Gnowergerup Brook (down from a current annual average salinity of 5381 mg/L at the Jayes Road gauging station on Gnowergerup Brook). Scenario 4 is significantly more effective than the next best management scenario, ‘strategic trees’ (Scenario 3), with projected 2030 salinities of 1861 mg/L in the Tweed River and 2154 mg/L in Gnowergerup Brook.

Projected responses of the catchments to land-use changes show:

- The salinities of the Tweed River and Gnowergerup Brook are not expected to increase significantly provided that there is no further clearing.

- Salinities of the Tweed River and Gnowergerup Brook can be reduced to annual means of 543 and 738 mg/L respectively by planting 59% of the cleared areas to trees, and the remainder to deep-rooted perennial pastures (Scenario 4). When taking into account flow-weighted mean data, stream salinity may be reduced to less than 500 mg/L by 2037.

- Achieving an average annual salinity reduction to around 500 mg/L can be achieved by targeting revegetation to areas producing the most salt; namely, the heavily cleared areas in the lower catchments, with the remaining cleared areas planted to deep-rooted perennials.

- The full benefits may not be achieved until around 35–40 years after planting.

- Returning the catchments to native forest or planting with plantation timber will return streams to ‘fresh’ water quality.

- Revegetation scenarios involve a compromise between salinity reduction and streamflow reduction.

This study focuses on conceptual salinity reduction options – to understand the extent of the land-use change needed to reach a salinity target.

Further work is needed on understanding the implications of the options: from economic, environmental and social contexts. As part of this, further work would be needed to ascertain the suitability of the land identified for commercial timber plantations and perennial pastures.

1 Introduction

The Blackwood River basin stretches from east of Kukerin to the coast at Augusta, and covers most of the Shires of Nannup, Bridgetown-Greenbushes, Boyup Brook, Wagin, Woodanilling, Katanning and Dumbleyung. As the majority of the middle to upper basin has been cleared and used for agriculture for a long time, surface water has become brackish to saline in these areas. The water quality improves downstream as the river flows through the more forested areas where it is diluted by the inflow of fresher tributaries. Much of the riparian environment is also moderately to severely degraded in the middle to upper basin (Department for Planning and Infrastructure 2004).

Both the Tweed River and Gnowergerup Brook are in the middle of the Blackwood basin and flow directly into the Blackwood River (Fig. 1). Land-use activities that influence stream salinity in these subcatchments eventually affect the salinity of the Blackwood River.

The purpose of this study is to define the current extent of salinisation of the Tweed River and Gnowergerup Brook catchments, and to project what may happen in the future under a range of salinity mitigation options (management scenarios). The effectiveness of each scenario is assessed by comparing it to the base case scenario (‘do nothing’ scenario).

The quantitative assessment is based on the parameters of streamflow, salt load and salinity. Other water quality and catchment issues are beyond the scope of this study.

1.1 Objectives

The objectives are:

- Assess the current (2007) salinity situation of the Tweed River and Gnowergerup Brook catchments.
- Project the salinity situation (salinity, salt load, streamflow) in 2030 and 2060 if no salinity mitigation measures are taken.
- Assess the impacts of a range of management scenarios on stream salinity.

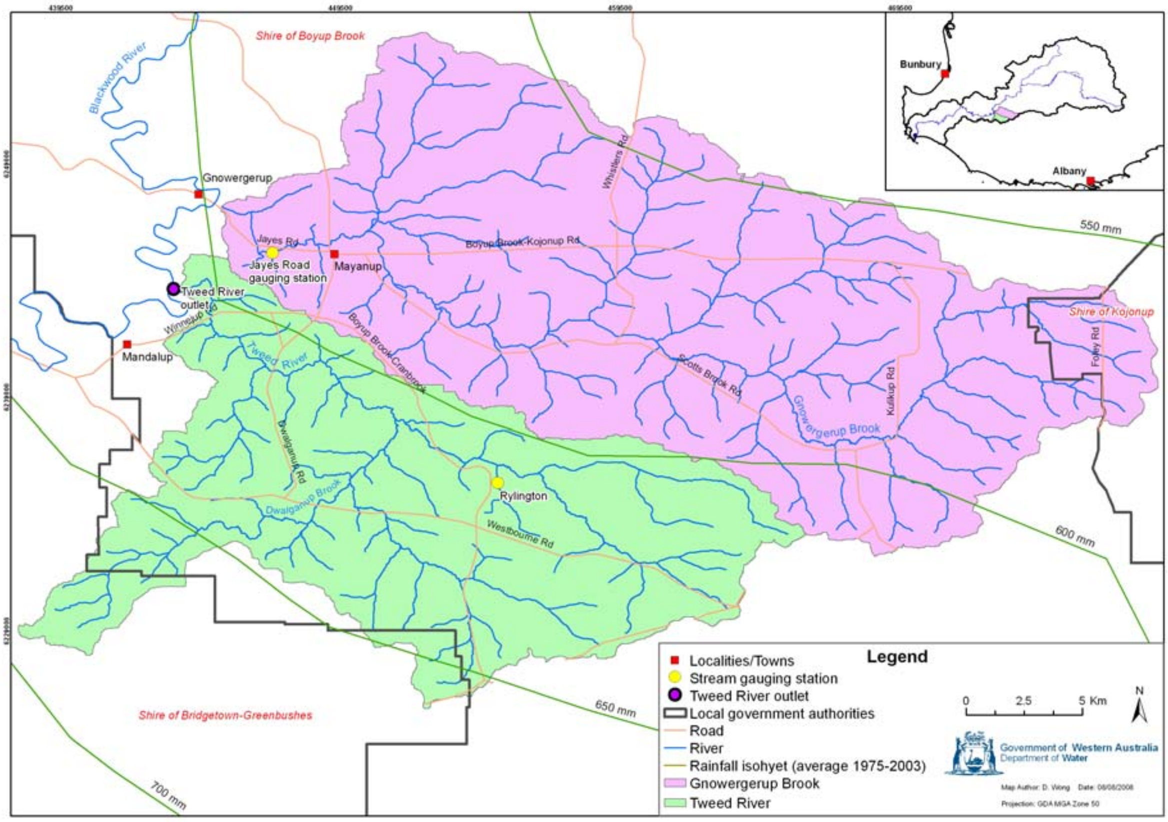

Figure 1 Location of the Tweed River and Gnowergerup Brook catchments

[AUSLIG 1997 & DOLA 2001]

1.2 The Blackwood Basin Group and South West Catchments Council

The Blackwood Basin Group (BBG) is a community-based organisation that delivers assistance to landholders to achieve sustainable land management across the Blackwood basin. The Group specialises in accelerating on-ground action through coordination of natural resource management and education. The BBG has good links to the community and agencies and works closely with government funding programs in delivering environmental management in the Blackwood region.

This project forms part of the South West Catchments Council's (SWCC) Regional NRM Investment Plan for 2005/2006. SWCC is a cooperative regional organisation aimed at identifying and coordinating strategic opportunities to achieve sustainable natural resource management in the south-west of Western Australia. The BBG works closely with SWCC in achieving its vision for delivering integrated natural resource management.

1.3 The Water Resource Recovery approach

The BBG has sought to use the Water Resource Recovery approach of the Department of Water to help in planning salinity management for these catchments.

The Department of Water (DoW) has adopted the following approach to salinity recovery (Fig. 2) and used it in planning water resource recovery in the Denmark, Collie, Warren, Helena and Kent catchments. It involves the following steps:

1. Situation statement — Analyses historical stream data, identifies the current and predicted salinity levels, and quantifies the hydrological impacts of a suite of conceptual management options (scenarios) for the study area.

2. Evaluation of management scenarios — Water quality objectives are defined and, in consultation with key stakeholders, potential management scenarios to meet these objectives are evaluated against the social, economic and environmental impacts of each scenario. Then a cost-benefit analysis of the most preferred scenarios helps to identify the most appropriate scenario/s for implementation.

3. Recovery plan — The major components of management scenarios to be implemented are identified and described, an implementation strategy developed and funding sources explored.

4. Implementation — Detailed planning, construction and operation of on-ground works done.

5. Monitoring and evaluation —Ongoing monitoring done to measure changes in stream salinity and to monitor the effectiveness of on-ground works.

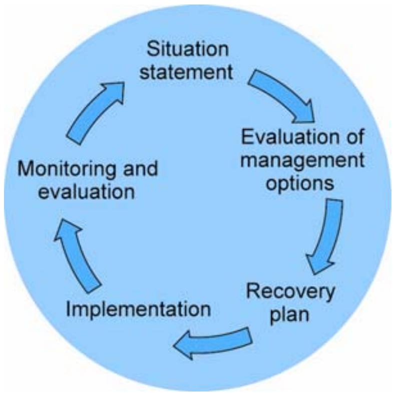

Figure 2 The Water Resource Recovery approach

Stakeholders are consulted throughout the recovery process to ensure that their needs and concerns are taken into account.

The Department of Water was asked by the BBG and SWCC to undertake the first step of the approach, the salinity situation statement. Subsequent steps and recommendations are for consideration of future work on salinity in the basin.

2 Catchment characteristics

2.1 Local government authorities and land vesting

The Tweed River and Gnowergerup Brook catchments have areas of approximately 236 and 377 km^2 respectively. About 90% of these two catchments are within the shire of Boyup Brook, with the remainder in the shires of Kojonup and Bridgetown-Greenbushes (Fig. 1).

Land vesting in these catchments is illustrated in Figure 3. Table 1 shows the land tenure based on freehold and non-freehold land.

Table 1 Freehold and non-freehold land by catchment

Catchment	Non-freehold		Freehold		Total area
	(km^2)	%	(km^2)	%	(km^2)
Tweed River	97	41	139	59	236
Gnowergerup Brook	59	16	318	84	377

2.2 Vegetation and clearing history

There was limited clearing in the Blackwood River valley between 1850 and 1900 to make way for orchards and in some cases pastoral leases that spread across the hill sides, and to extract high value wood products. It was not until the 1950s with the advent of more advanced broadacre clearing practices that there was large scale clearing for cereal cropping and sheep grazing in the east and in the west, more intensive land uses such as beef cattle, dairy, horticulture and cropping (Mayer et al. 2005).

By 1979, 61% of the two catchments had been cleared. In 1998, when the cleared area had reached 65%, clearing of native vegetation was halted and, by 2007, the cleared area had reduced to 59%. There are marked differences in the extent of clearing. Gnowergerup Brook was more heavily cleared and is now 70% cleared. Tweed River has more remaining native vegetation and in 2007 41% was cleared.

The predominant native vegetation complex consists mainly of jarrah–marri (*Eucalyptus marginata–Corymbia calophylla*) woodlands interspersed with wandoo (*E. wandoo*) woodlands. Riparian vegetation mainly consists of flooded gum (*E. rudis*) while paperbark (*Melaleuca rhaphiophylla*) forms a dense understorey at the edge of some streams (Fig. 4; Appendix A) (CALM 2001; CALM 2005).

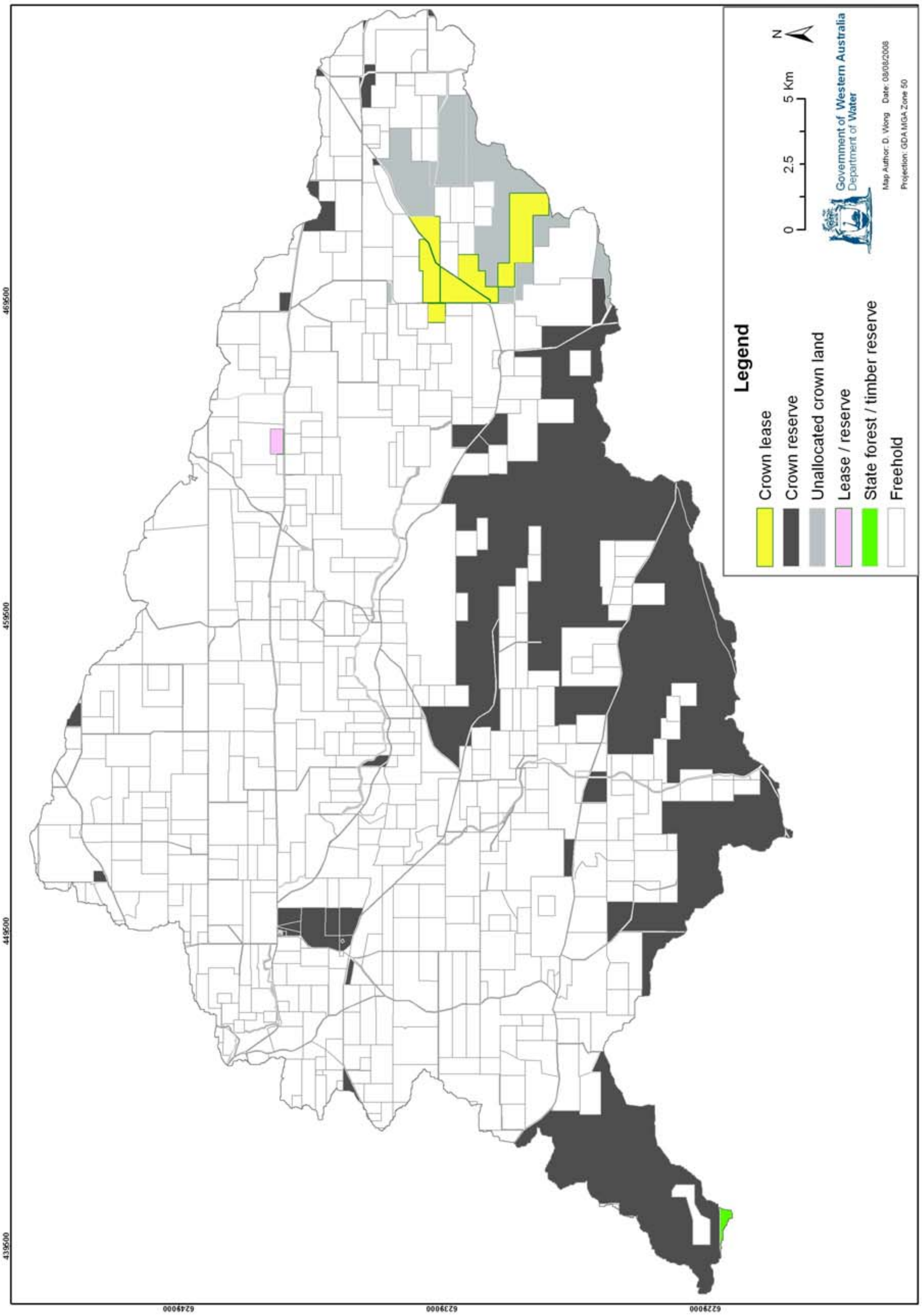

Figure 3 Land vesting in the Tweed River and Gnowergerup Brook catchments

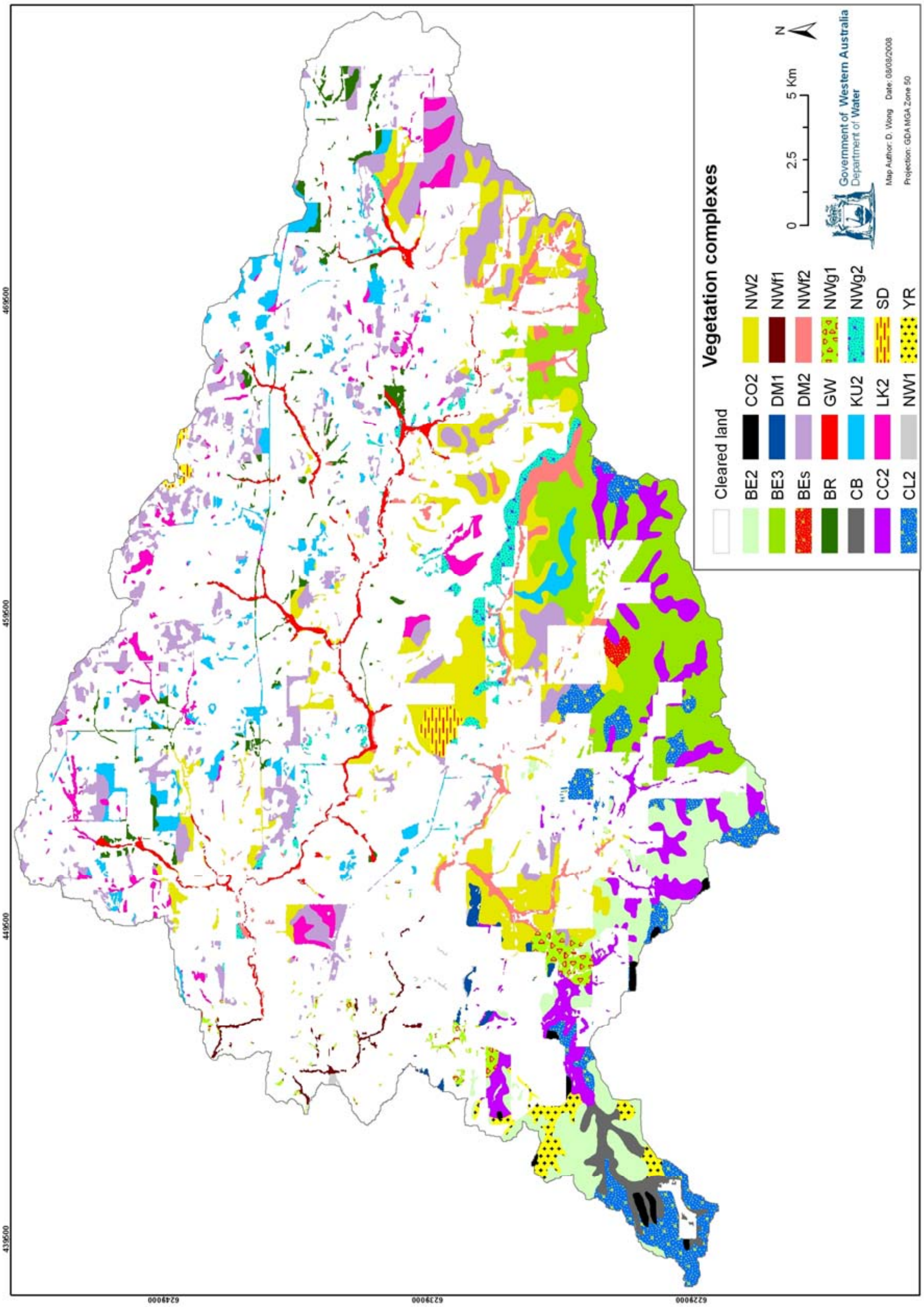

Figure 4 Current extent of native vegetation (see Appendix A for description of complexes)

[DLI 2008, CALM 2001, CALM 2005*]*

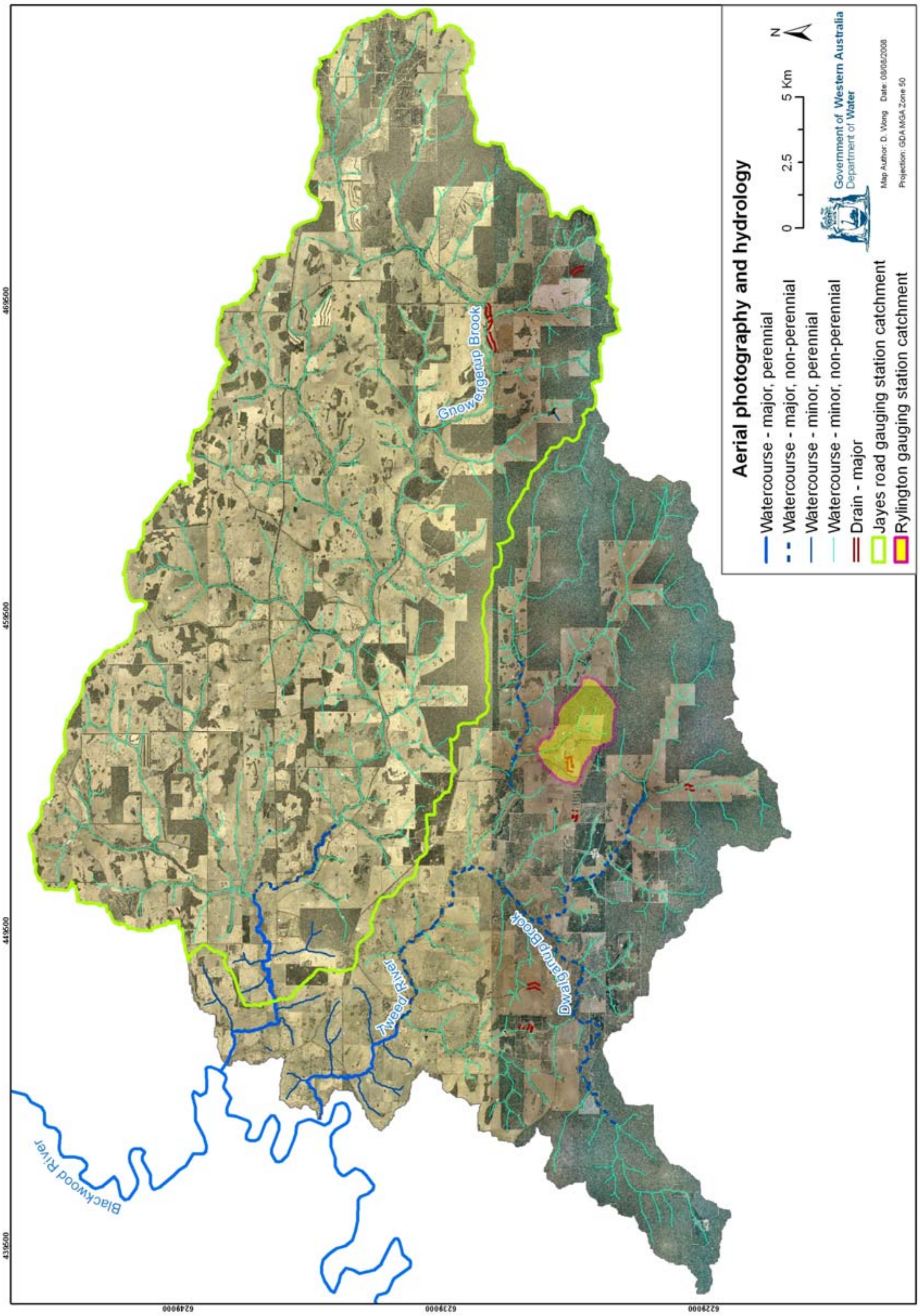

Figure 5 Aerial photography (2003 & 2004) and hydrology

[Landgate 2003, 2004a & b]

In 2007, the total tree cover (native forest and plantations) for the catchments was 139 ha (Tweed River) and 112 ha (Gnowergerup Brook). Land use in the catchments has changed with time with plantations established and harvested (Tables 2 & 3; Fig. 6).

Table 2 Land-use history: forest/plantation cover

Year	Vegetation cover (ha)	
	Tweed	Gnowergerup
1979	119.9	118.0
1985	116.5	98.7
1988	115.0	107.5
1992	108.5	93.4
1994	108.0	89.4
1996	122.5	103.1
1998	119.9	92.7
2000	127.2	116.2
2002	136.1	122.9
2004	136.9	129.0
2005	136.4	118.9
2006	141.3	123.4
2007	139.1	112.0

The total cleared and vegetated areas for each year were calculated (Table 3). A negative net area indicates more clearing than planting, whereas a positive net area indicates more planting than clearing (Table 4).

Table 3 Land-use history: plantations added/harvested

Year	Net area vegetated (ha)	
	Tweed	Gnowergerup
1979–1985	-3.4	-19.3
1985–1988	-1.5	8.8
1988–1992	-6.5	-14.1
1992–1994	-0.4	-4.0
1994–1996	14.5	13.7
1996–1998	-2.7	-10.4
1998–2000	7.4	23.5
2000–2002	8.9	6.7
2002–2004	0.8	6.1
2004–2005	-0.5	-10.2
2005–2006	4.9	4.6
2006–2007	-2.3	-11.4

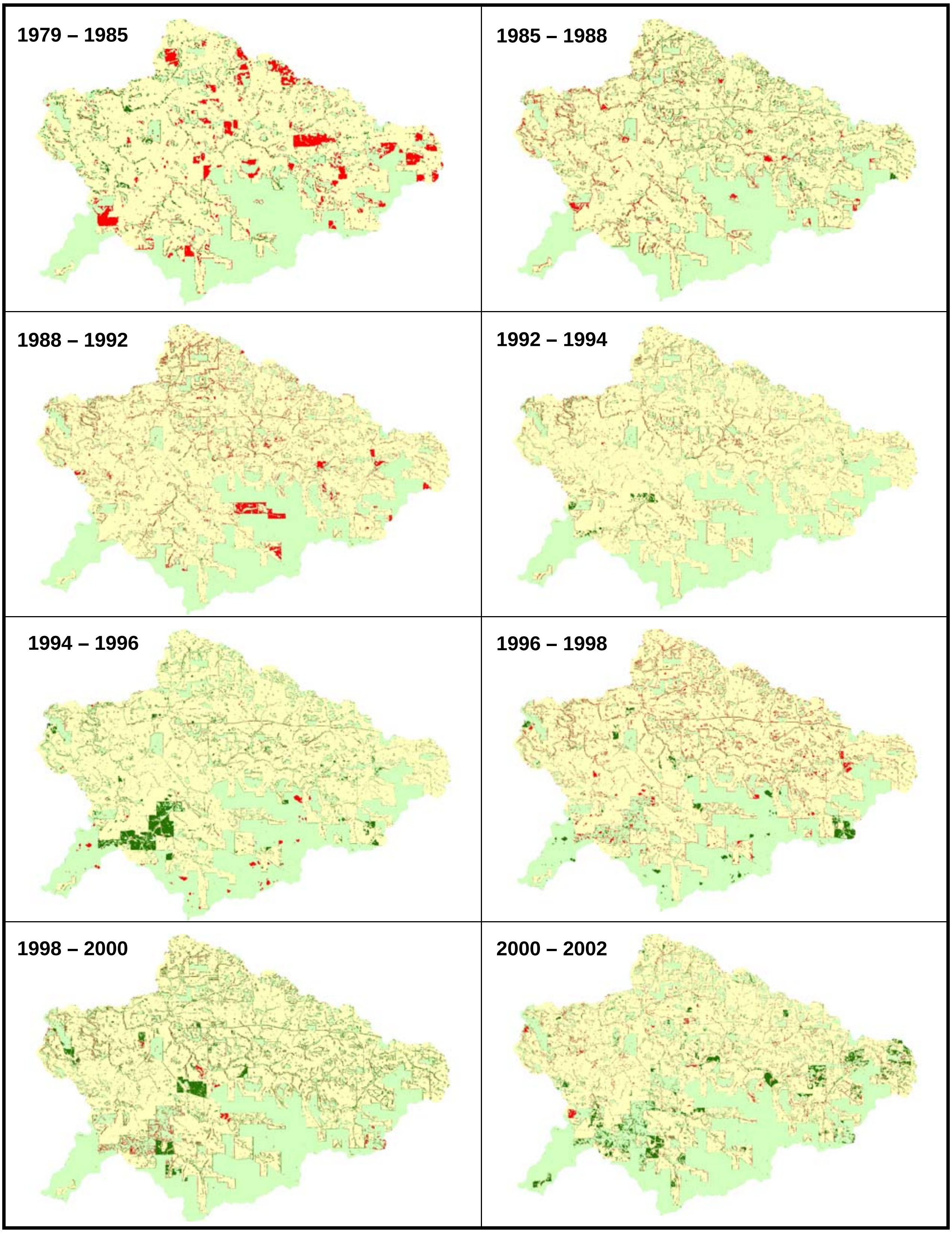

Figure 6 Land-use history: planted and cleared areas (continued next page)

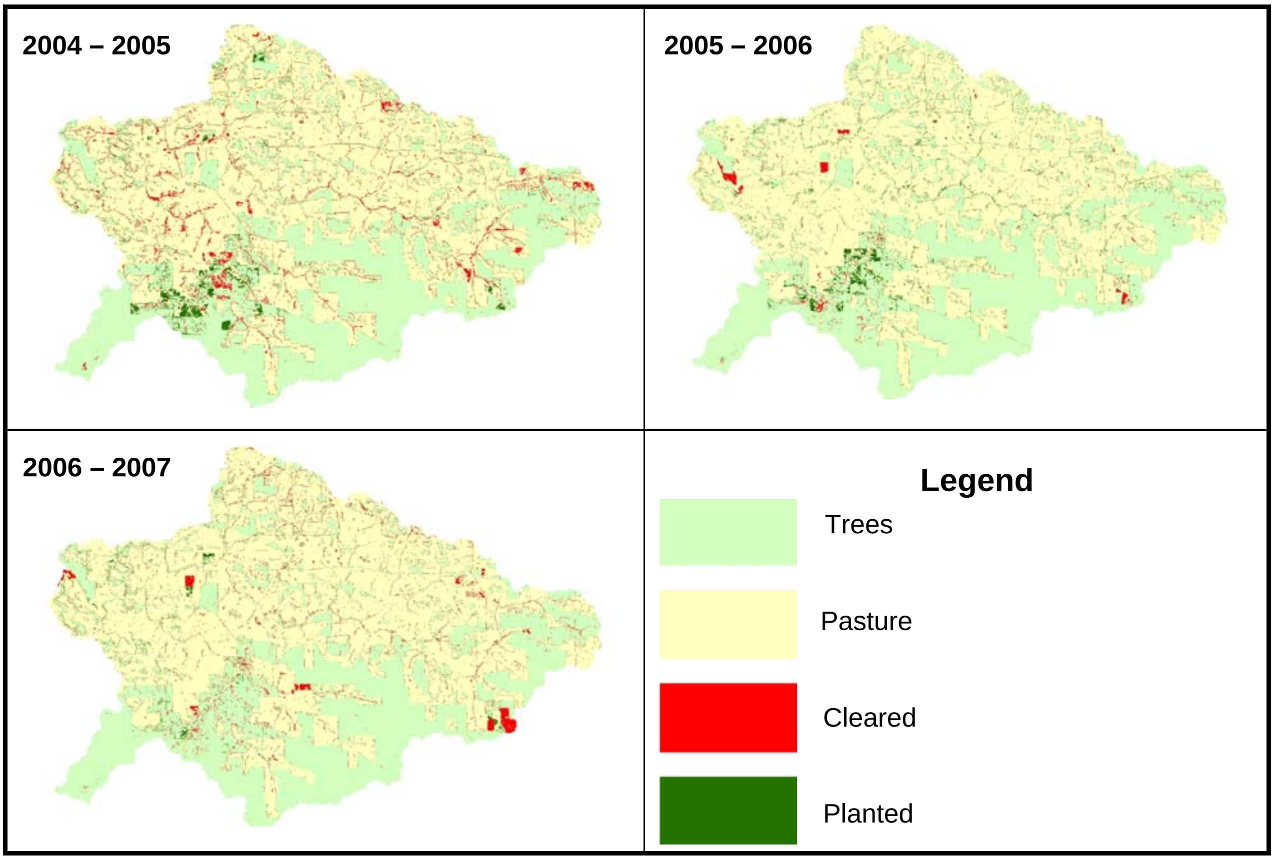

Figure 6 Land-use history: planted and cleared areas (continued from previous page)

2.3 Surface drainage

The watercourses of these two catchments drain into the Blackwood River; most are ephemeral, especially in the upstream parts (Fig. 5) and only further downstream are they perennial.

2.4 Climate

The climate is Mediterranean-type, characterised by hot, dry summers and cool, wet winters (Figs 7 & 8). There are 22 rain gauging stations in and in the vicinity of the catchments. Monthly catchment rainfall averages across the Tweed and Gnowergerup were obtained by interpolating data from these rain gauging stations (Fig. 7). The annual rainfall range is 550–650 mm (Fig. 9) at meteorology station M009556 (1.5 km west of the intersection of Westbourne and Winnejup Roads).

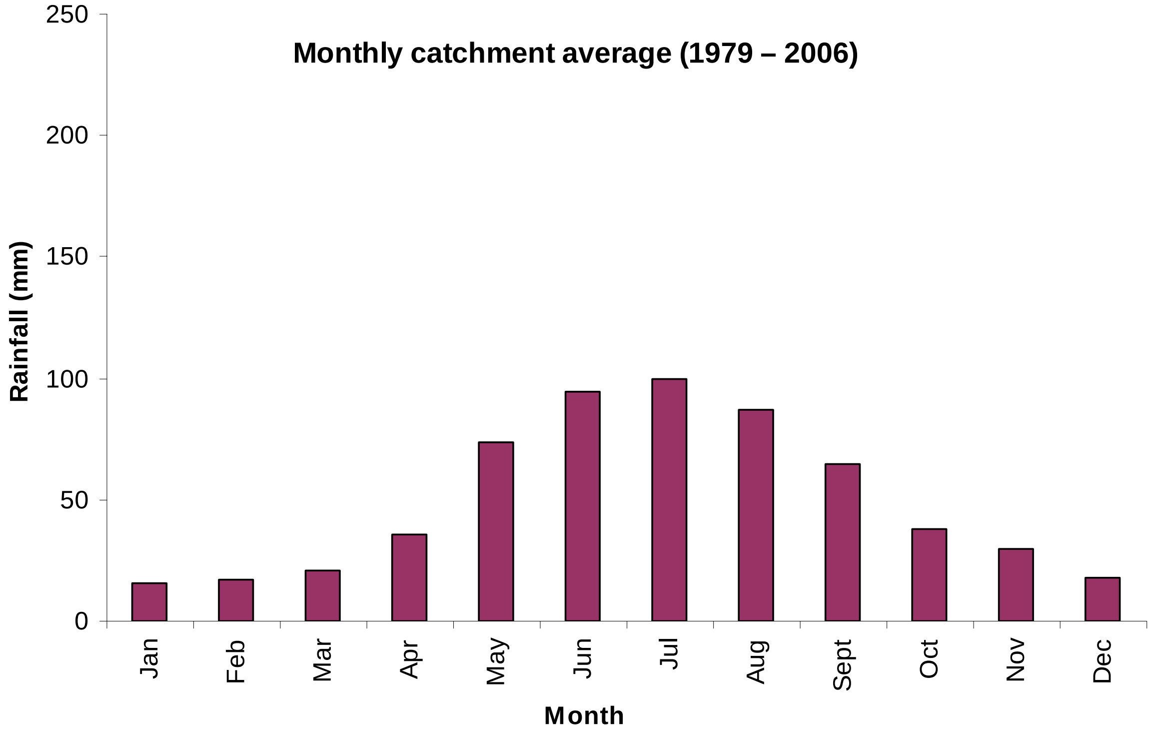

Figure 7 Mean monthly rainfall for the Tweed and Gnowergerup catchments

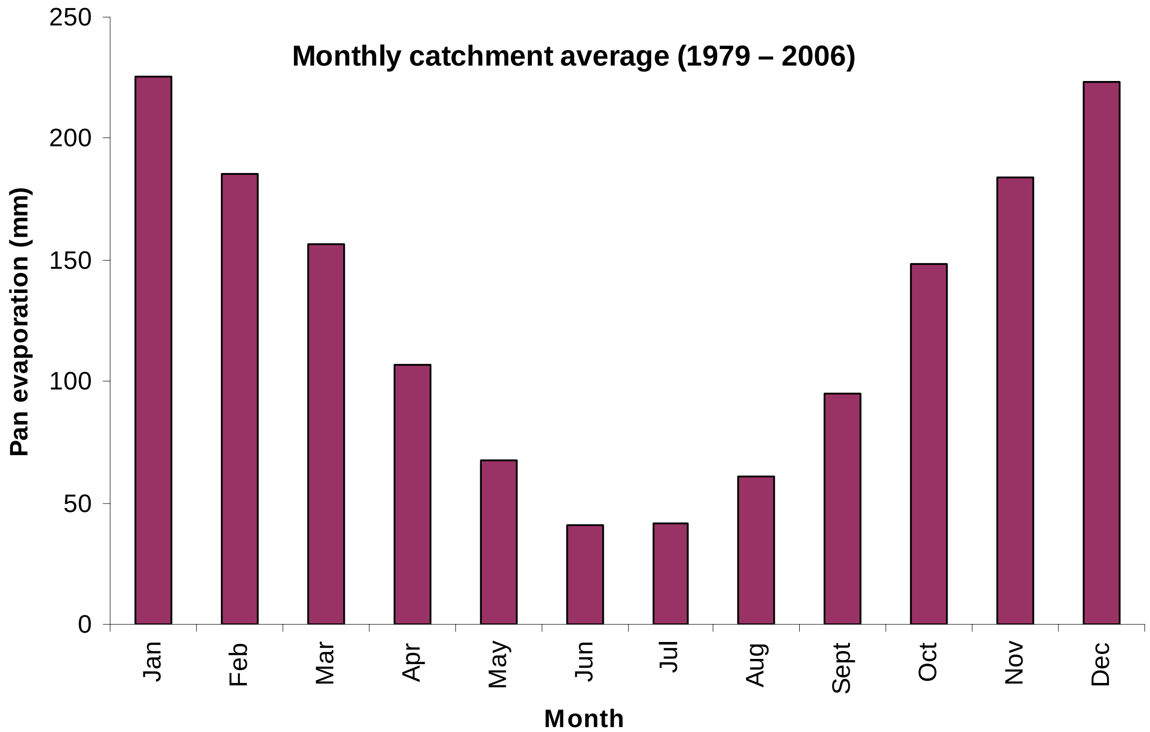

Figure 8 Mean monthly pan evaporation for the Tweed and Gnowergerup catchments

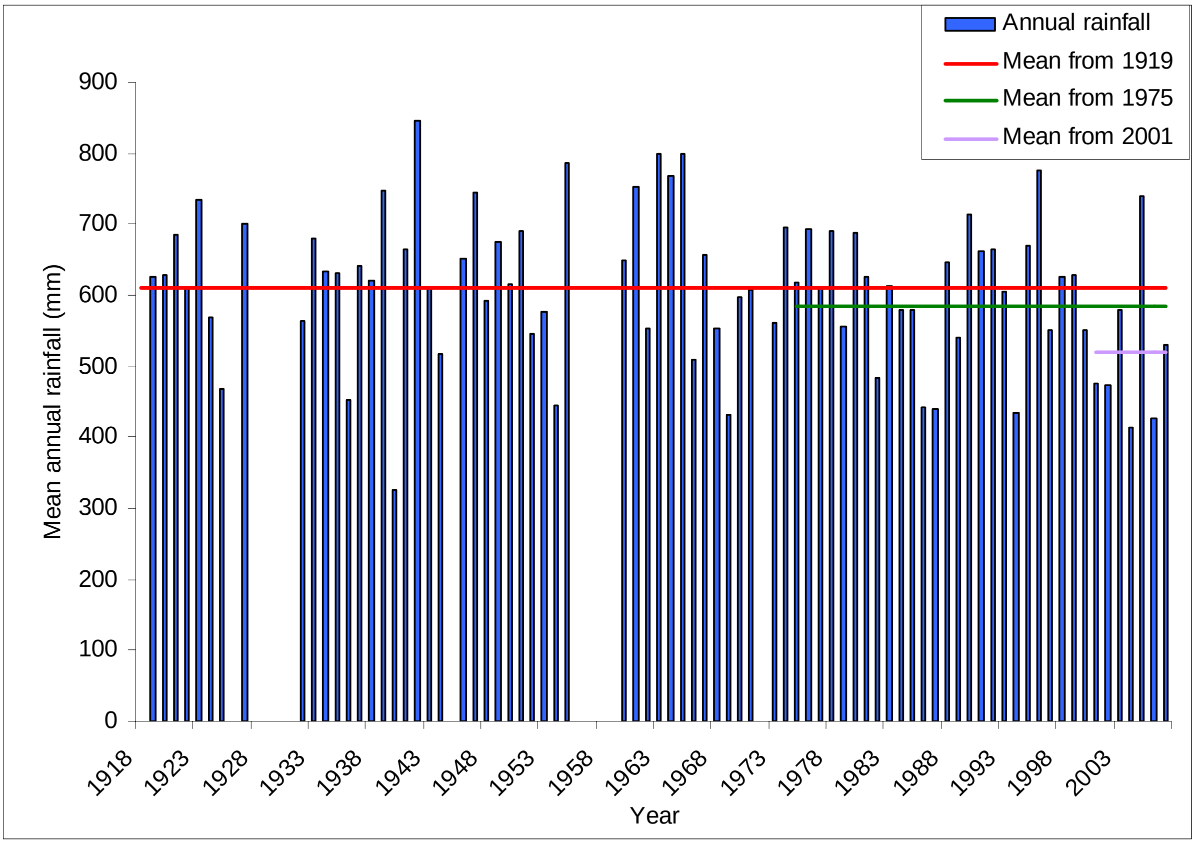

Figure 9 Annual rainfall at rain gauging station 009587 for 1919–2007 (missing columns represent years with poor quality or no data)

2.5 Geology and hydrogeology

The Tweed and Gnowergerup catchments fall within the hydrogeology 1:250 000 map sheet zones of Collie and Pemberton (Rutherford 2000; De Silva 2004). They have deeply incised valleys with some rock outcrops with the remainder being lateritic Darling Plateau remnants containing poorly drained flats and broad swampy depressions (Tille et al. 2001).

The catchments consist mainly of Archaean and minor Proterozoic basement rocks of the Yilgarn Craton which covers more than 85% of the Blackwood River catchment (De Silva et al. 2000). Overlying surficial sediments are primarily of Tertiary or Quaternary age. The quartzite basement rocks are gneissic (An) and granitoid (Ag) complexes displaying various stages of weathering profiles 30–60 m thick. A number of Proterozoic dykes and veins have intruded the basement rocks and the Boyup Brook Fault dissects the north-western edge of the Gnowergerup Brook catchment (De Silva et al. 2000; Rutherford 2000; De Silva 2004) (Figs 10 & 11).

The main aquifers occur in the gneissic and granitoid and weathered profiles and in joints and fractures of crystalline rocks. However, faults, fractures and joints are commonly localised and have limited groundwater potential, as does the weathered profile of crystalline rocks which display variable, but usually low, porosity and hydraulic conductivities (De Silva et al. 2000; Rutherford 2000).

Groundwater recharge is through direct infiltration from rainfall, surface runoff from outcrops or from throughflow originating from upslope sections of the weathering profile. Discharge is highly variable and ranges from 0.05 to 0.5 m/d. It is reliant on the topography of the bedrock, the intensity of jointing and fracturing, the lithology of the rock and the amount of recharge (Rutherford 2000; De Silva 2004). As granitic rocks tend to weather to a sandier profile and gneissic rocks to a clayey profile, granitic rocks can produce higher discharge yields (De Silva 20004). Discharge occurs in main drainage lines and in areas where the watertable intersects the land surface with groundwater flows occurring through the Permian Basin sediments and Eocene, Cainozoic and Quaternary surficial sediments (Rutherford 2000). This is also occurrence of discharge resulting in the formation of springs and soaks (wetlands) which may increase with continued rises in the watertable (Rutherford 2000).

Groundwater salinities throughout the weathered profile are typically brackish to highly saline (1000–16 000 mg/L), gradually increasing from west to east across the Blackwood River catchment. In the western areas, higher rainfall, undulating topography and perennial watercourses increase recharge and effectively flush salt from the catchments. Lower rainfall and poorly drained landscapes with low relief in the eastern regions of the Collie have resulted in the storage of salts and poor groundwater quality. There is general topographic control on salinity within the subcatchments where lower landscape areas (i.e. valley floors) have higher groundwater salinities (Rutherford 2000; De Silva 2004).

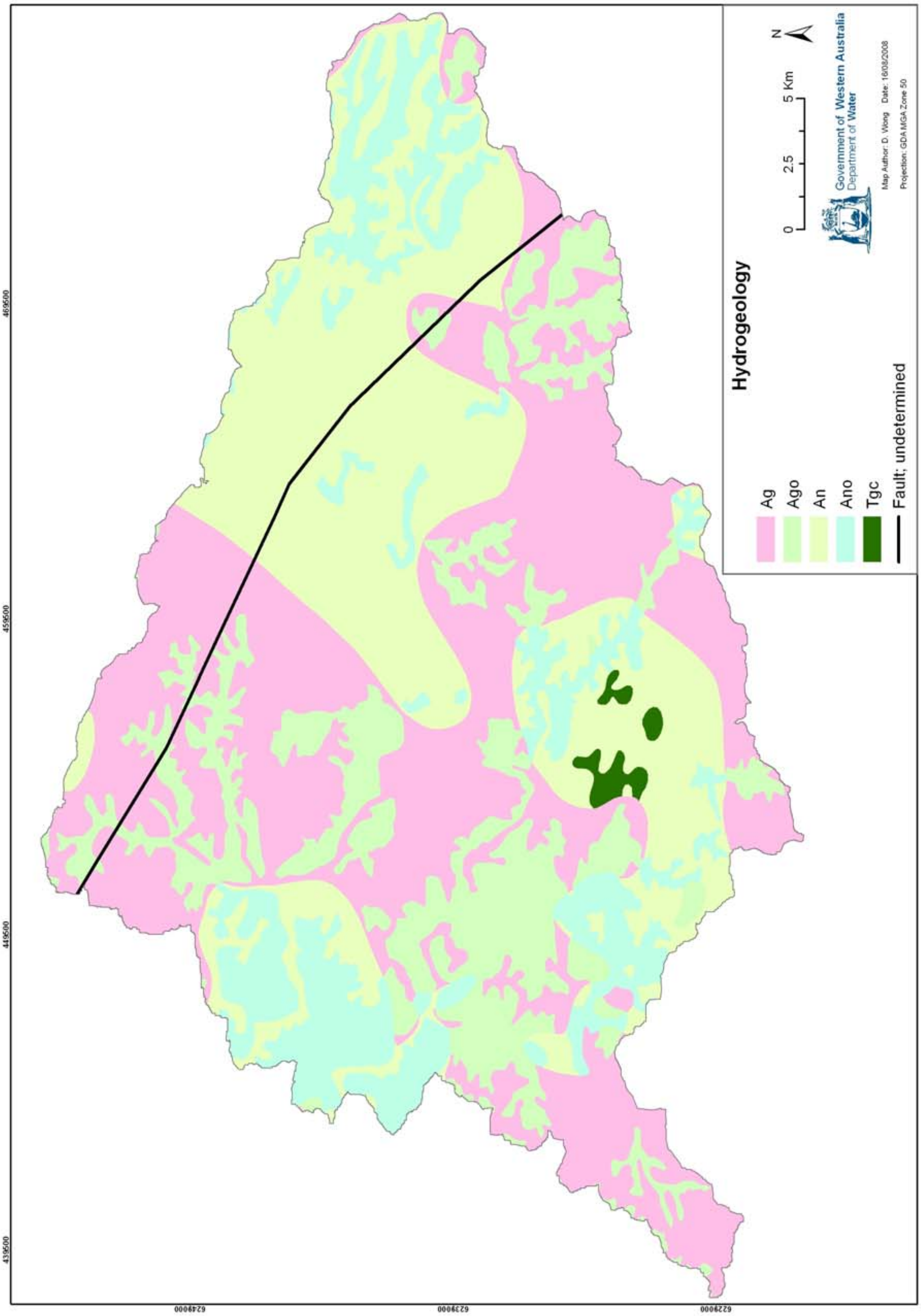

Figure 10 Hydrogeology (see also Appendix B)

[GSWA 2002]

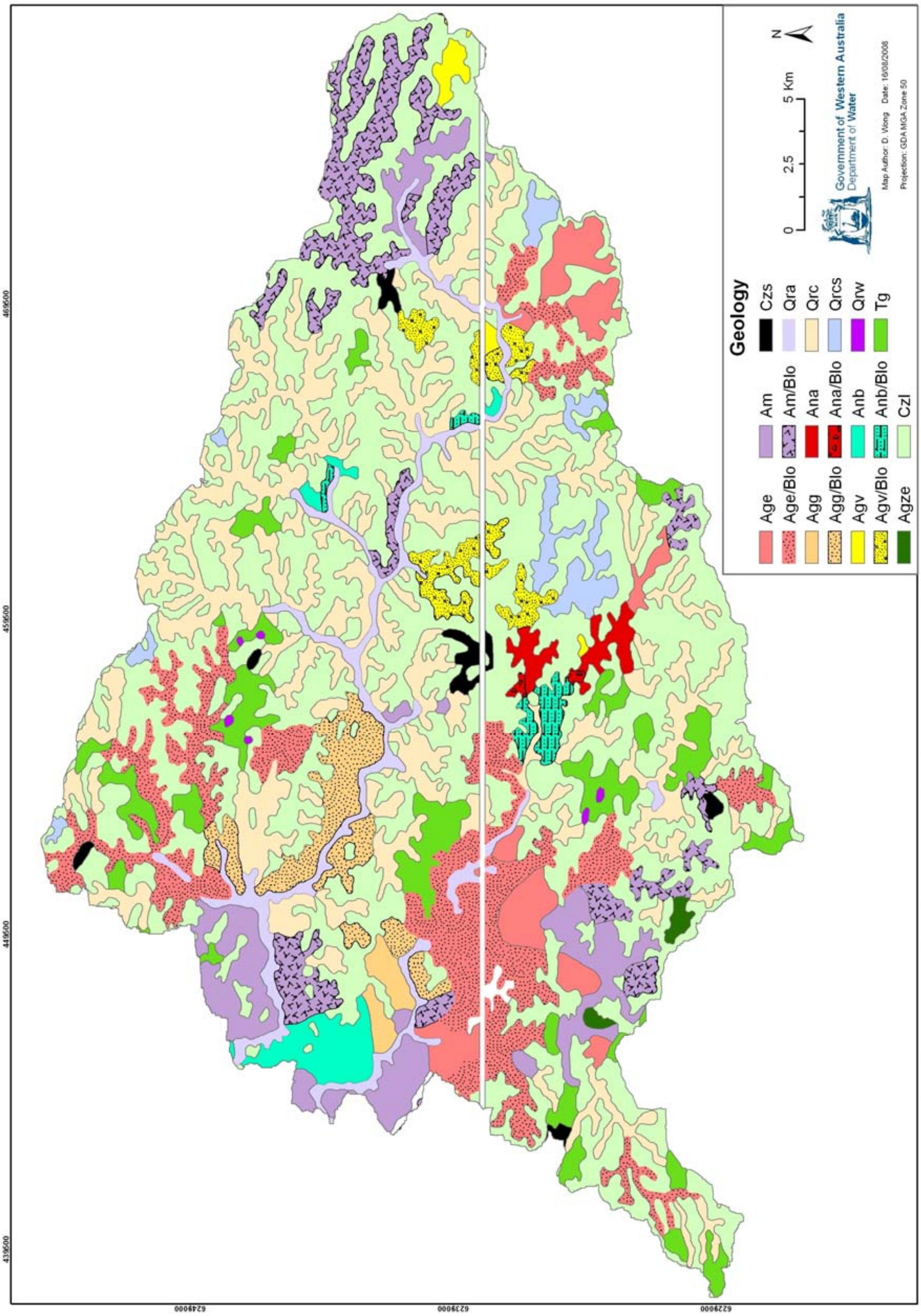

Figure 11 Geological units (see also Appendix C)

[GSWA 2006]

2.6 Soil-landscape systems

The Tweed and Gnowergerup catchment areas encompass three major soil landscape systems: the Boyup Brook Valleys, Eulin Uplands and Perup Plateau Systems (Fig. 12).

Soil systems of the Eastern Darling Range Zone, which includes the Boyup Brook Valleys and Eulin Uplands systems, are mainly formed on laterite (over granite), truncated laterite, rock weathering in-situ and deposited sediments. The Boyup Brook Valleys System was formed where the Blackwood River had dissected the Eulin Uplands System to form shallow–moderately incised valleys 15–50 m deep.

Soils of the Boyup Brook Valleys System consist of duplex sandy gravels, grey deep sandy duplexes, loamy gravels and brown deep loamy duplexes. The duplex nature of the soils is such that the sand/gravel overlies a clay layer, or loam grading into clay (Grein 1995).

The Eulin Uplands System consists of plateaus and plateau remnants (mostly lateritic) containing ridges and divides. Duplex sandy gravels and loamy gravels with minor wet soils, semi-wet soils and grey deep sandy duplexes are found here. Pockets of sandy soils are also present (BBG 2006b).

The Perup Plateau System is in the southern part of the Tweed River catchment. The terrain consists of undulating lateritic plateaus with extensive swampy plains and depressions. Soils are formed on granite and Tertiary sediments. The soils consist of loamy gravels and gravelly and sandy yellow duplex soils, with yellow solonetzic soils (subsurface clay accumulation, rich in sodium). Podzols (leached soils) are present in the swamps.

All three soil systems can be further subdivided into the soil subsystems mapped and described in detail in Appendix D.

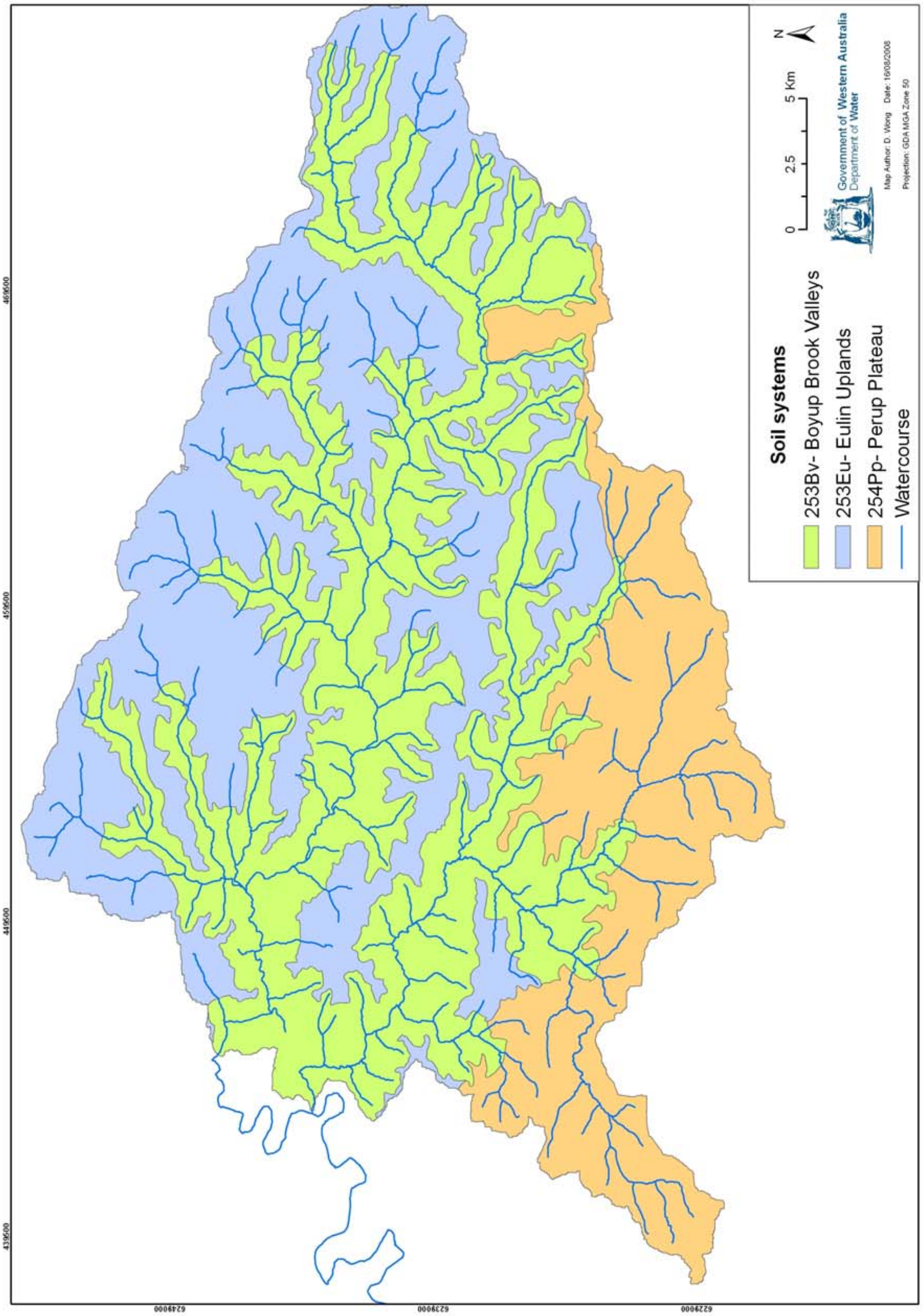

Figure 12 Soil systems

[AGWA 2002]

2.7 Topography

The topography of both catchments is characterised by dissected, rolling terrain. The elevation varies from 145 metres (m) AHD for the lower valley floors to about 350 m AHD in the high country at the edge of the catchments (Fig. 13).

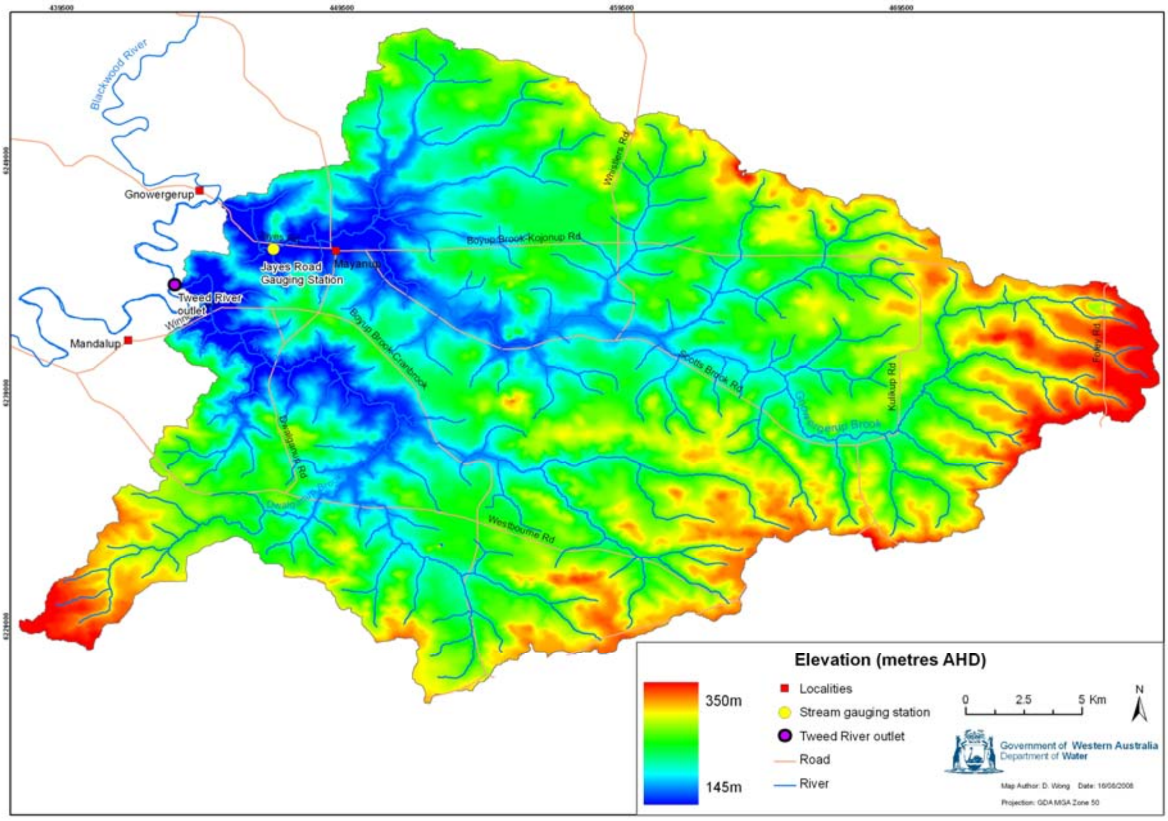

Figure 13 Topography

3 Flow and salinity characteristics

3.1 Data

Streamflow data at the Jayes Road gauging station on Gnowergerup Brook has been monitored since 1998. Salinity was also recorded at the site. The catchment area above Jayes Road is 368.43 km^2. An experimental gauging station at Rylington on the Tweed River (Fig. 5) has been operating since 2003, but to date only four full years of data have been recorded. In addition, there was spot sampling in the Tweed River and Gnowergerup Brook at various locations in November 2007.

3.2 Salinity and flows

The average annual flow-weighted salinity (1996–2006) for the Gnowergerup Brook catchment was 5382 mg/L (Fig. 14), though daily records show salinities up to 25 737 mg/L. Salinities are elevated during autumn when the first seasonal rains 'flush' out salt that has accumulated in stream beds and river pools during the low-flow summer period (Fig. 15). Salinity varies considerably through the year, with monthly averages from 4215 in August to 16 329 mg/L in March.

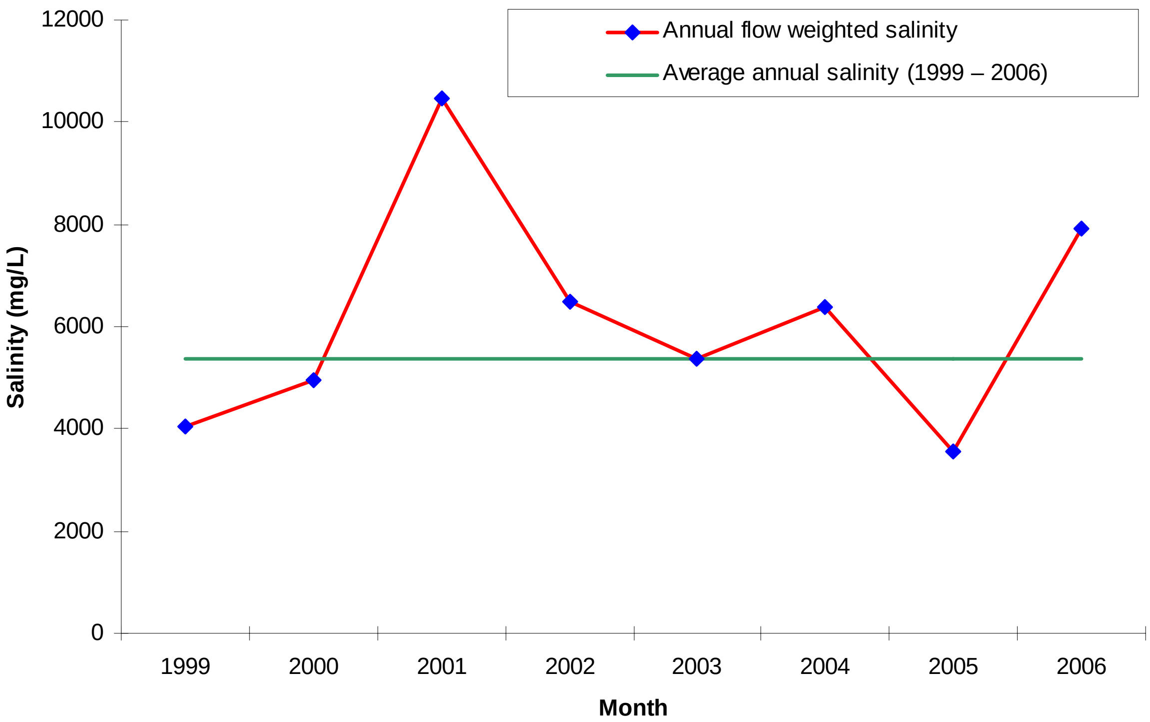

Figure 14 Annual salinities for Gnowergerup Brook at the Jayes Road gauging station

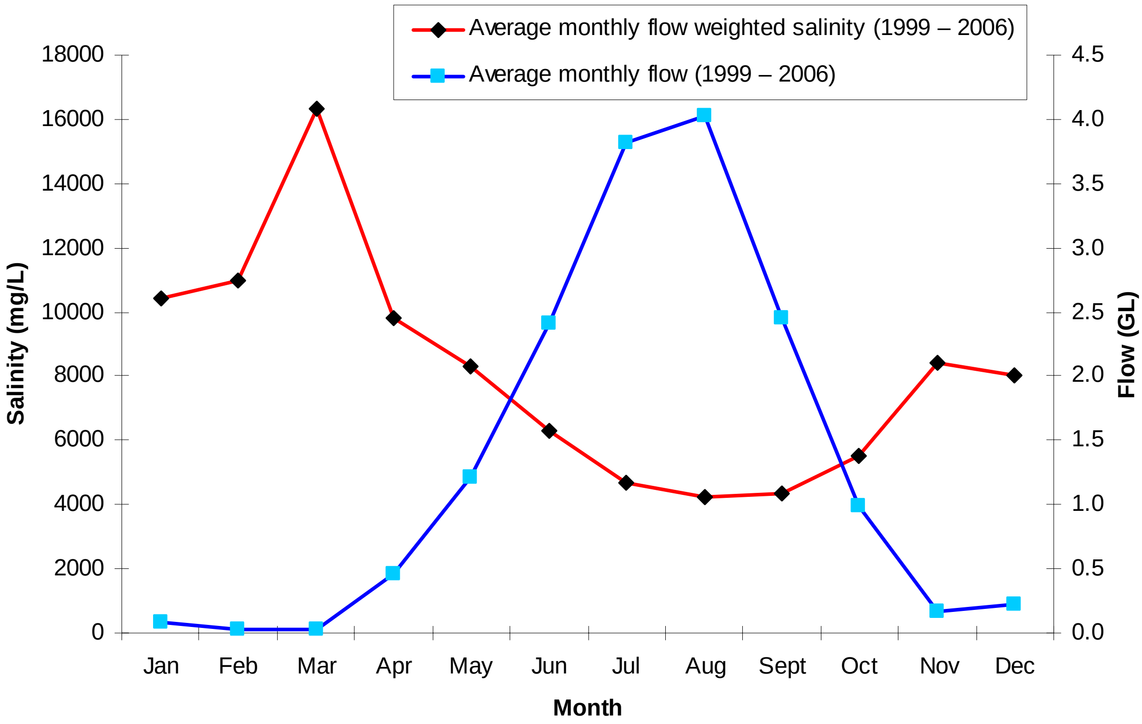

Figure 15 Average monthly flow and salinity at the Jayes Road gauging station

The mean annual streamflow of Gnowergerup Brook was 16 GL with the highest annual flow recorded in 2005 when 30 GL flowed through the Jayes Road gauging station (Fig. 16). Streamflow volumes are seasonal and so vary considerably across the year: lowest during March, with a monthly average of 0.024 GL, and highest during August at an average of 4.021 GL (Fig. 15).

Although salinities during winter are lower as a result of higher streamflows, the Gnowergerup Brook still carries significant salt loads. July had the highest monthly average salt load (18 kt) and February the lowest (average 0.29 kt). Total annual salt loads through Jayes Road were related to streamflows (Fig. 17); however, in low-flow years salt loads tended to be proportionately higher.

The Rylington gauging station (Tweed River) has 6.09 km^2 catchment area and the average salinity (2004–07) was 3616 mg/L, with the annual salinity range 2090 mg/L in 2005 to 5656 mg/L in 2006. Annual streamflows ranged from 122 in 2006 to 428 ML in 2005 (a high rainfall year in the catchment).

Although streamflows and salinities varied markedly between years, salt loads discharged and measured at the Rylington gauging station were relatively stable over the four years of monitoring: the highest was 923 t in 2004. In 2007, which had a significantly lower streamflow of 155.5 ML compared to 428 ML in 2005, the salt load was 860 t.

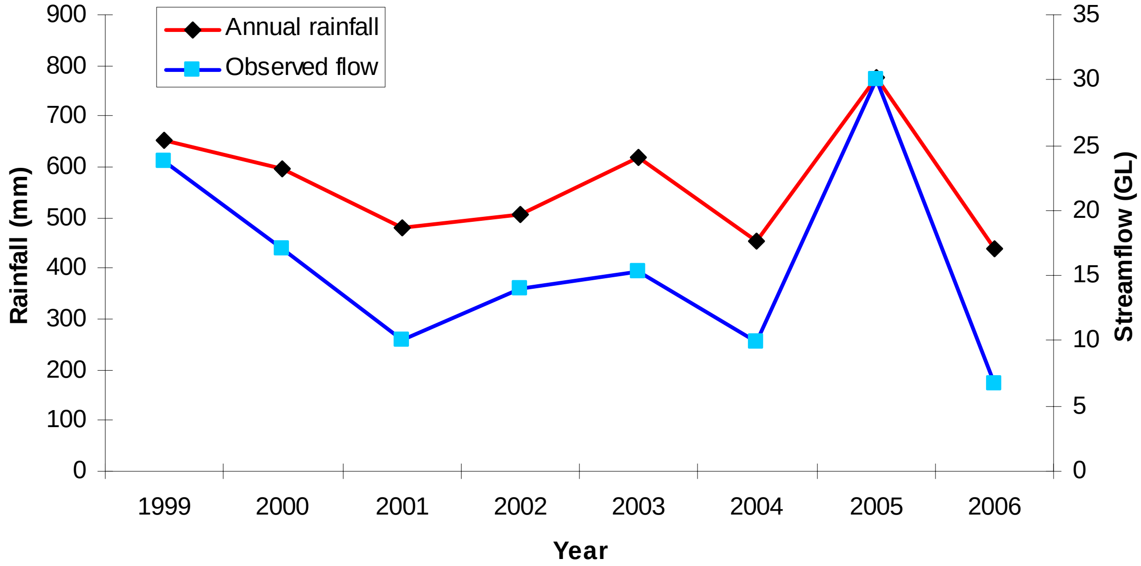

Figure 16 Average annual streamflow and rainfall at the Jayes Road gauging station

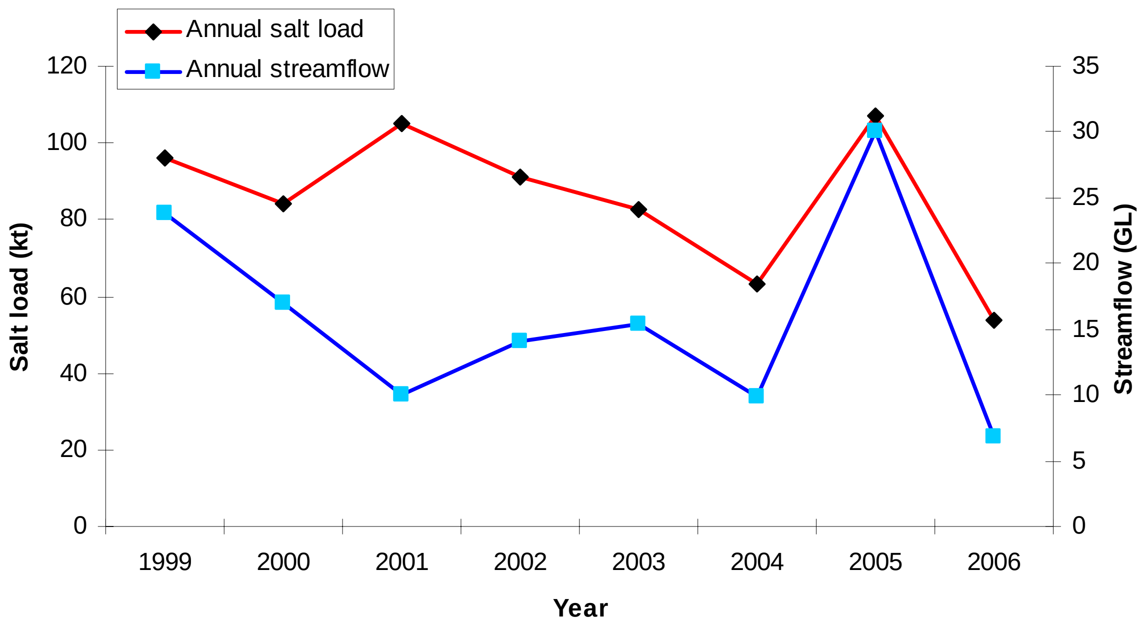

Figure 17 Annual salt loads and streamflow at the Jayes Road gauging station

Spot samples for salinity and pH were taken in the two catchments on 25 October 2007. The highest salinity recorded, 9914 mg/L, was in the upper Gnowergerup catchment at the Kulikup Road bridge. Lower salinities (7692 mg/L) were recorded at the Jayes Road gauging station. Only one site on the Tweed River was sampled: at the Boyup Brook–Cranbrook Road bridge, where the salinity was 6332 mg/L. The pH at all sites was slightly alkaline, from pH 8.4 in the upper Gnowergerup to pH 7.8 at the Jayes Road gauging station.

4 Catchment modelling

4.1 What is modelling?

A model is a mathematical tool to simulate flow and salinity changes that may result from land-use or climate changes. An effective model incorporates a good understanding of landscape processes, reliable input data and, when these do not exist, sound assumptions or data from other sources.

In the case of the Tweed River catchment, as good quality calibration and validation data were not available, the model was constructed around assumptions and data taken from the Gnowergerup Brook catchment.

Subcatchments were modelled to validate and build confidence in the modelled results by comparing observed data with projections at the Jayes Road gauging station. The results are the best projections of catchment processes relating to salinity and streamflows that we are able to gain because the models are closely tied to ‘real world’ data.

4.2 The LUCICAT Live model

To describe the current salinity situation and simulate future salinity trends it is essential to know the salinity, volume of water (streamflow) and mass of salt (salt load) from these subcatchments. These three parameters are the key indicators in describing catchment stream salinity.

Projections of streamflow, salt load and salinity were derived using the dynamic Land Use Change Integrated Catchment model LUCICAT (Bari 2005). The model can provide long-term simulations of various land-use scenarios and includes the effects of salt leaching. The model is run until hydrological equilibrium is reached for a given scenario. In some cases the model needs to be run for simulation periods of more than 100 years before catchment hydrological equilibria are reached.

The model calculates the daily salt and water balances following land-use changes across a range of catchment scales. It takes into account the spatial distribution of topography, vegetation characteristics, basic soil types, rainfall, evaporation and soil salt storage.

The model’s main feature is division of a catchment into subcatchments called management units and even smaller areas called response units (Fig. 18). Response units are the key component or building block of the model (Appendix E).

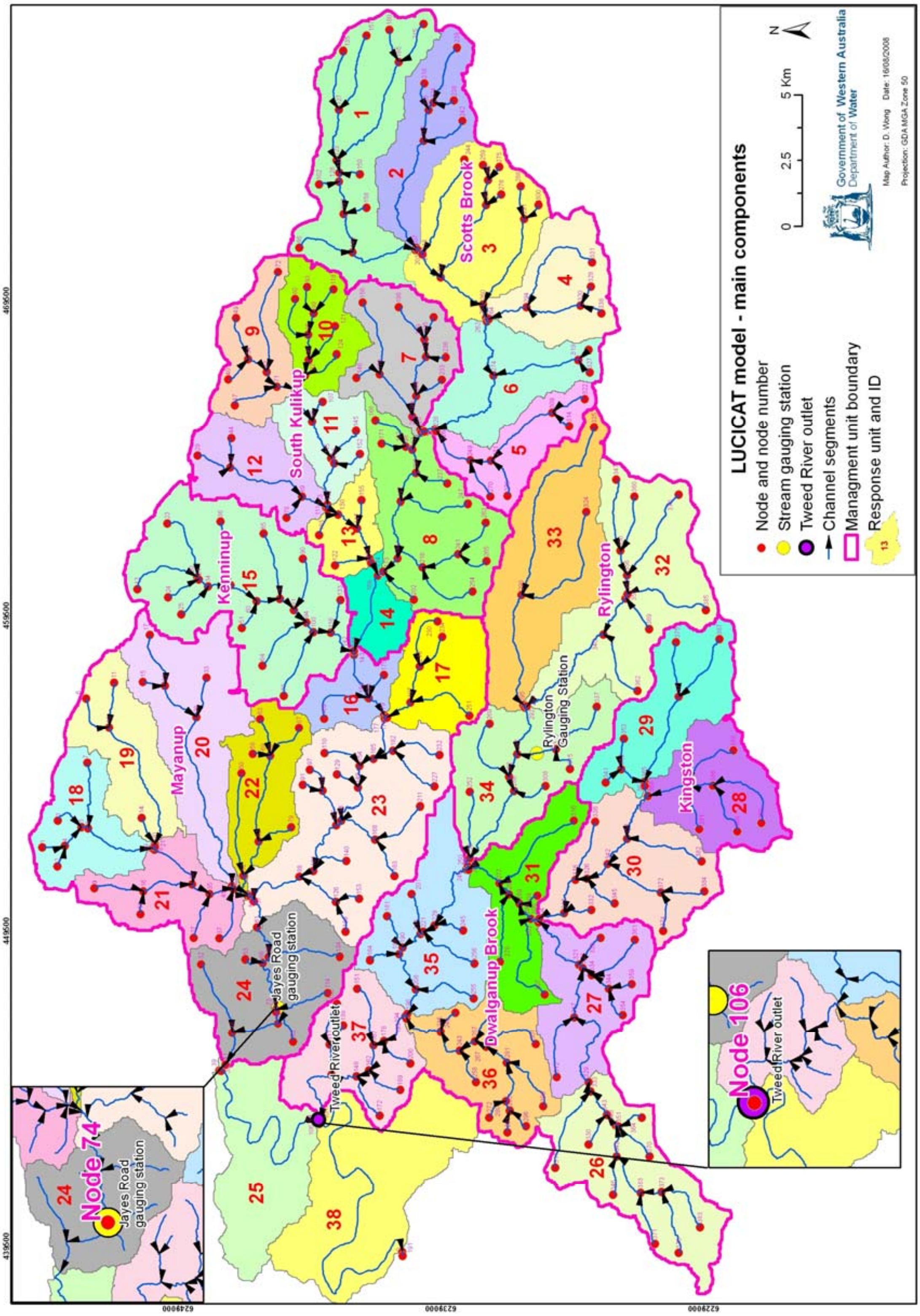

Figure 18 Main components of the LUCICAT model, management units, response units, channel network and nodes

4.3 Response units and management units

The smallest parcel of land modelled is the response unit. Response units are simply subcatchments, are based on factors including overall catchment size (scale of the modelling to be performed), topography, surface hydrology and in some cases land use and geology (Appendix E). To get an outlet which includes flows from both the Tweed River and Gnowergerup Brook catchments, it was necessary to extend the modelled catchment to include a section of the Blackwood River. Thirty-eight response units were generated for the Tweed/Gnowergerup catchments (Fig. 18; see also Appendix E).

The catchments were divided into ‘management units’ for reporting the results of modelling to show the effects of a specific land use-option on a targeted ‘management unit’. This allows for a more focused and therefore effective approach to catchment salinity mitigation.

Management units were selected by grouping response units in a way that each management unit had only one hydrological outlet. With several configurations available, the Blackwood Basin Group (BBG) was consulted for the most suitable grouping. The BBG based the groupings on local knowledge of the land characteristics and the social aspects of catchment management (location of stakeholders).

Figure 18 shows the location and names of the management units. The Rylington, Kingston and Dwalganup Brook management units form the Tweed River catchment, while the Gnowergerup Brook catchment consists of Scotts Brook, South Kulikup, Kenninup and Mayanup. The flow or routing between management units and response units is illustrated in Figure 18 and explained in Appendix E.

4.4 Calibrating and validating the model

Calibration of the LUCICAT Live model involved adjusting the values of a few parameters to get the ‘best fit’ between the modelled and observed data with respect to salt load, streamflow and salinity. These parameters are explained in the LUCICAT Technical Manual (Bari 2005). Seven years of measured data (1999–2006) for the Jayes Road gauging station were compared to the modelled data at Node 74. Node 74 was selected as it is at the same location as the actual Jayes Road gauging station and its catchment is therefore the same. Hence a direct comparison could be made between the modelled and observed data here. The location of this gauging station, node 74 and its catchment are shown in Figure 18.

Modelled and observed 30-day moving average and annual salt loads, streamflows and salinities are closely correlated (Figs 19–22). This is confirmed by the high correlation coefficients between the modelled and observed data (Appendix E). Once this was achieved, the model was sufficiently calibrated for the next step: scenario modelling.

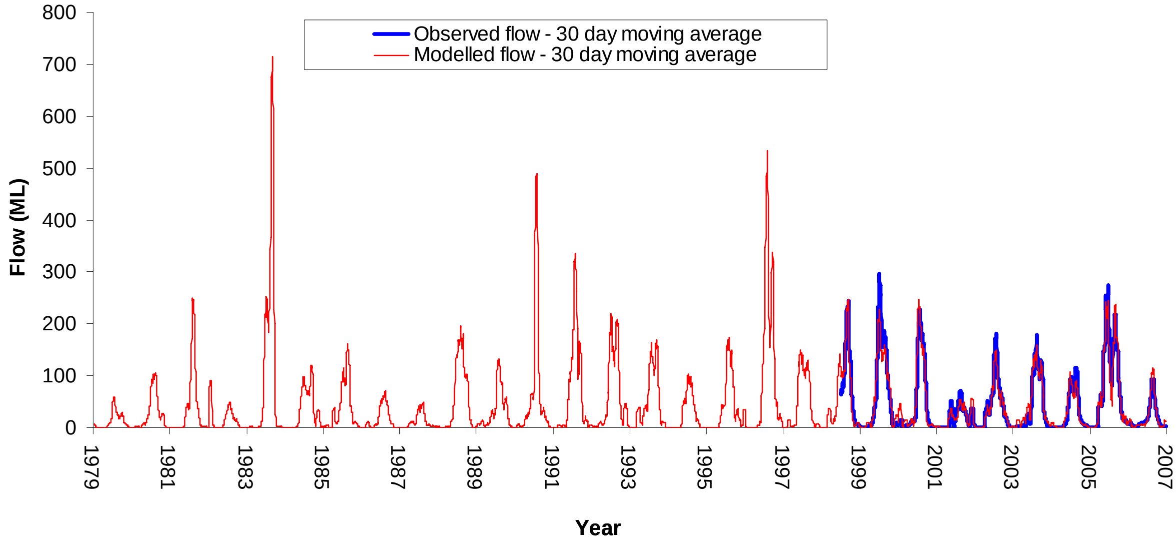

Figure 19 Comparison between observed and modelled 30 day moving average flows

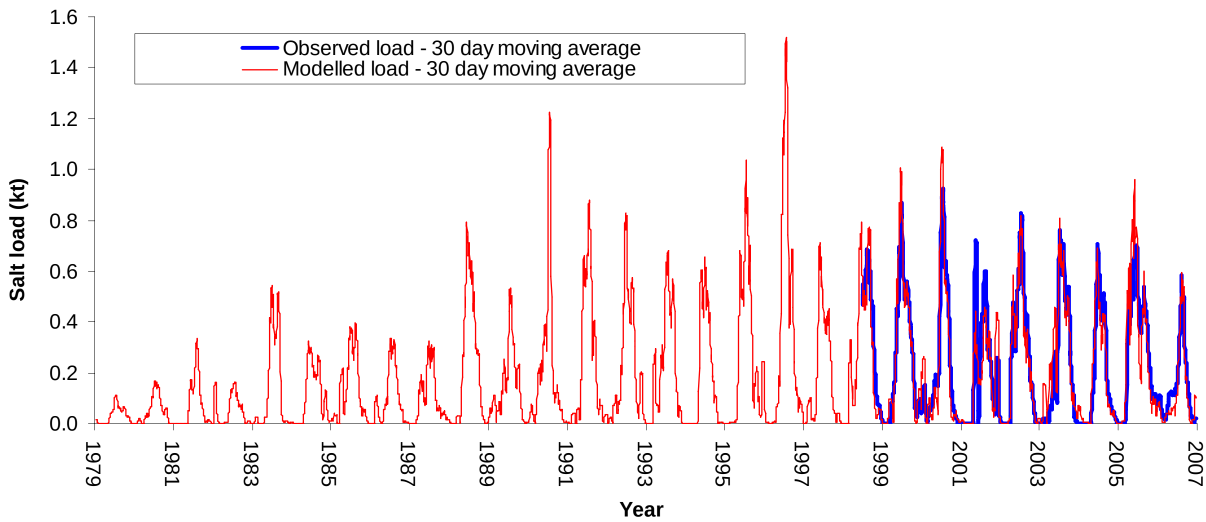

Figure 20 Comparison between observed and modelled 30 day moving average salt loads

4.5 Modelling scenarios

The dynamic LUCICAT model was used to simulate the changes in salinity and flow that may occur if the land use changes. Results from running various vegetation scenarios can be used for management decisions or for understanding the catchment. To estimate their ‘effectiveness’, they are compared to the ‘base case’ or ‘do nothing’ scenario.

In the ‘base case’ scenario, the assumption is that no further land-use changes occur after 2007; that is, there is no further clearing or planting after 2007. The ‘base case’ is used as a control to gauge the effect of any particular scenario on salinity and flow and to project the future catchment situation based on the current land use.

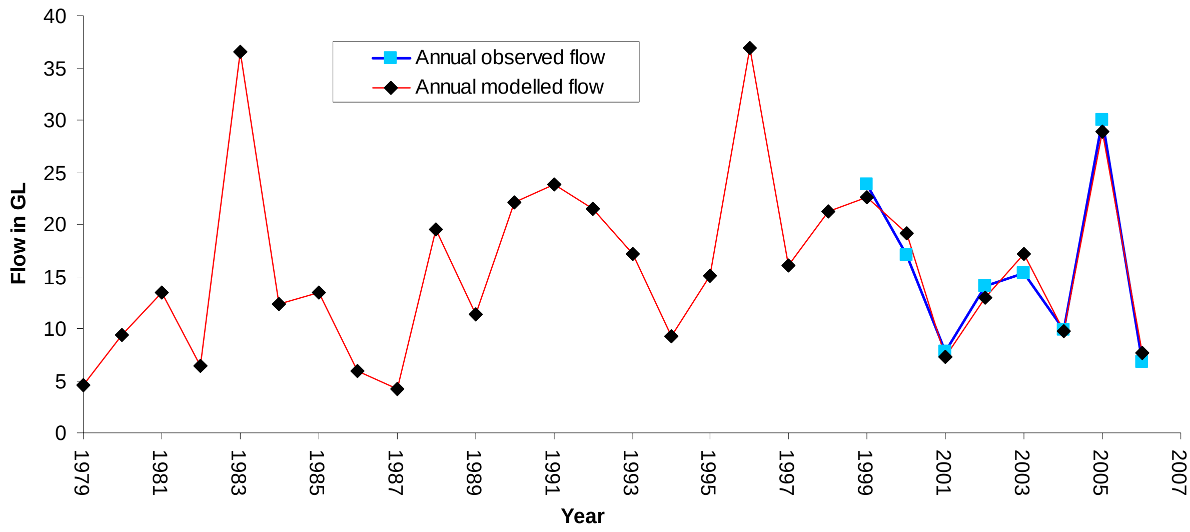

Figure 21 Comparison between observed and modelled annual flows

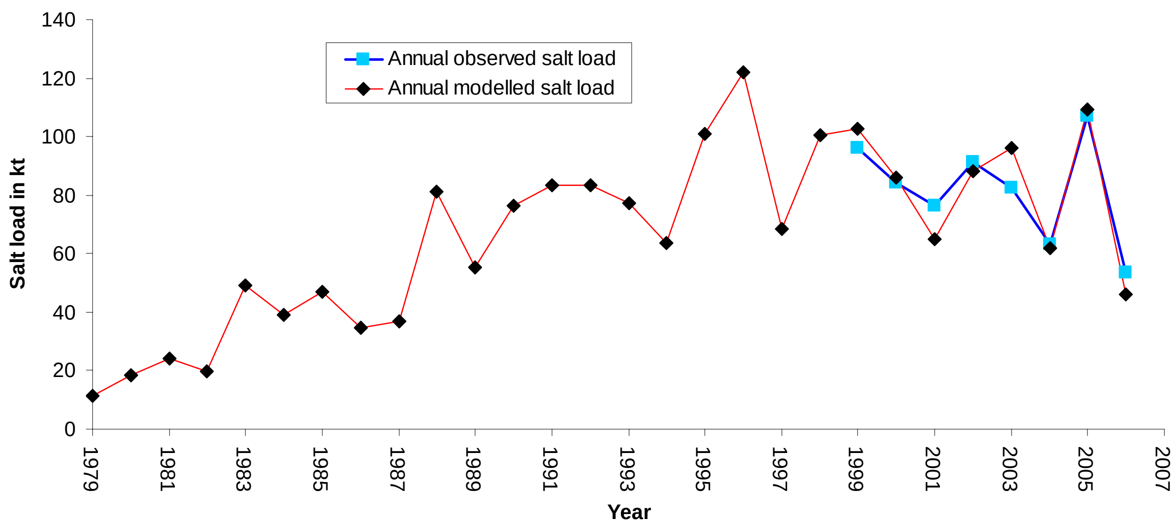

Figure 22 Comparison between observed and modelled annual salt loads

The modelling calibration run using the 1979–2006 stream gauging and rainfall data (Fig. 23a) was re-run (Fig. 23b) to extend the modelling into the future (using the 2007 land-use data) by repeating the rainfall data (Figs 23c & d); the modelled results being the 'base case'. The same process was repeated for the scenario runs (Figs 23e & f), but using a modified 2007 land-use file. The land-use file composition (pasture, forest, trees and perennials) was altered according to the scenario.

Comparisons can be made between the 'base case' and scenarios (Fig. 23c with 23e & 23d with 23f) that remove the effect of climate change as the same historical climatic data is repeated for all modelling runs.

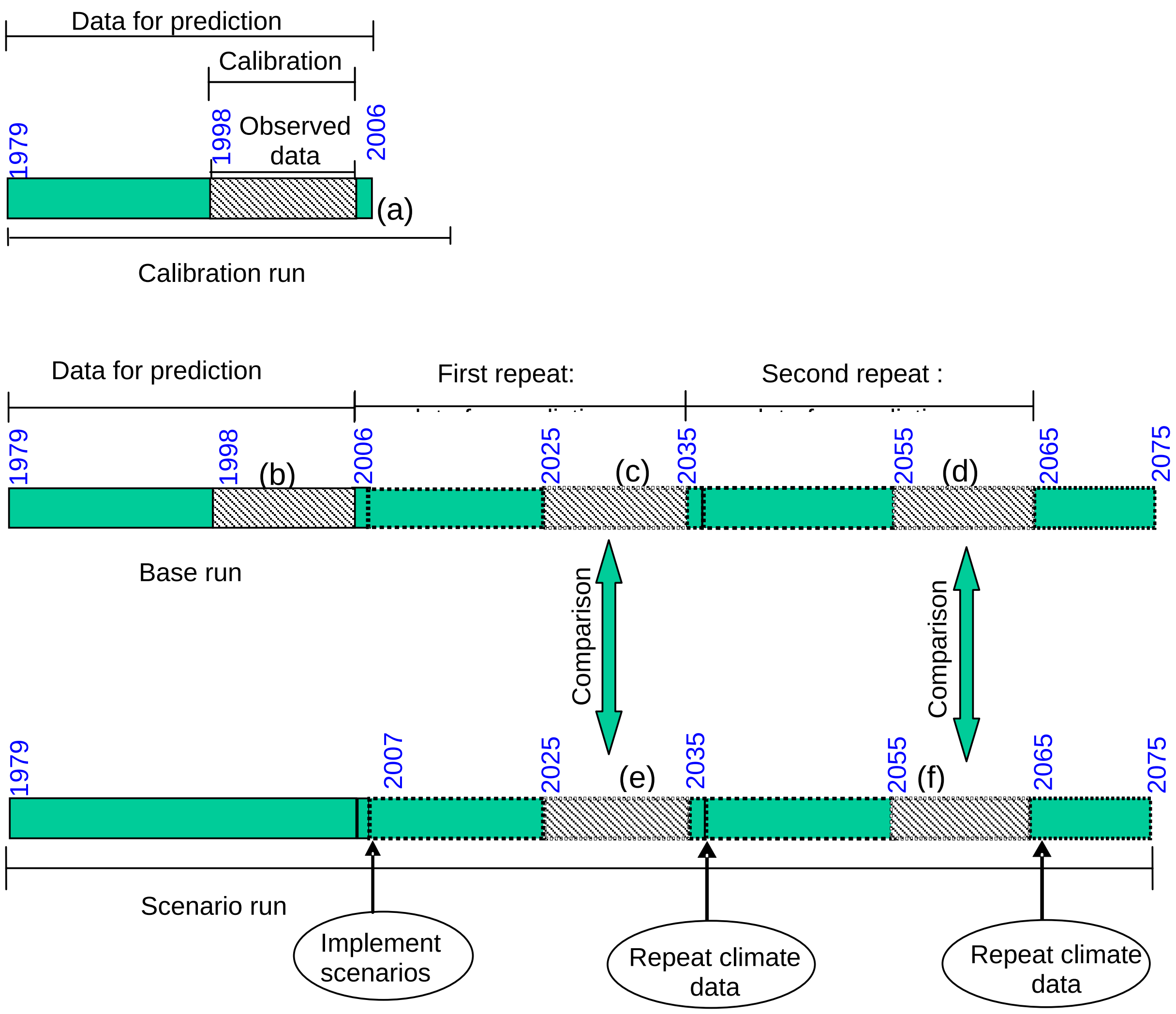

Figure 23 Conceptual diagram of (a) calibration (b) calibration re-run (c) short-term and (d) long-term 'base case' projections (e) short-term and (f) long-term scenario projections

4.6 Current salinity situation

The modelled base case scenario data (2002–12) for flows, salt loads and flow-weighted salinities were calculated for each management unit to provide the current salinity situation as at 2007 (Fig. 24).

The management units that contribute the most salt and flow to the Blackwood River are Mayanup and South Kulikup. Salinities are highest in Kenninup, followed by South Kulikup and Mayanup (Fig. 24).

Contribution of salt to the Blackwood River is influenced by the size, flow and salinity of the management units. So the larger but less saline Scotts Brook management unit contributes more salt than the smaller but more saline Kenninup (Fig. 24).

Gnowergerup Brook contributed an annual average (based on 1999–2006 Jayes Road stream gauging data) of 15.9 GL of flow and 85 kt of salt to the Blackwood River. This compares to an annual flow and annual salt load of 6.1 GL and 26 kt respectively in the Tweed River catchment for the same period as estimated from modelled data.

The Gnowergerup Brook and Tweed River catchments contribute a combined 111 kt of salt and 21.9 GL of flow to the Blackwood River. This is about 11% of the total annual salt load of the Blackwood River, despite these catchments having a combined area and flow of only 3% and 4% respectively of the Blackwood basin.

4.7 Assumptions

It is important to note that, while the modelling results are ‘best estimates’ only and do not account for future climate change, they are a means for assessing the relative effectiveness of the scenarios. However, the model takes into account current climate change in terms of rainfall reduction because the model uses the drier more current 1979–2006 rainfall period rather than an earlier wetter period (Fig. 9).

The modelled results for the current situation (2007) and in 2030 and 2060 have the variations smoothed out by averaging the data over 11 consecutive years unless otherwise stated. Salinities are flow-weighted (total salt load divided by total flow). The results do not imply exact values but are calculated values to approximate the current and projected salinity situations.

Assumptions include:

- All trees are planted in 2008 and reach maturity in 2020.
- There is no harvesting.
- Tree plantations and local native forest within a response unit have the same LAI.
- The water demand of plantation trees is summed from planting to full maturity.
- Perennial pastures and annual pastures within a response unit have the same LAI.

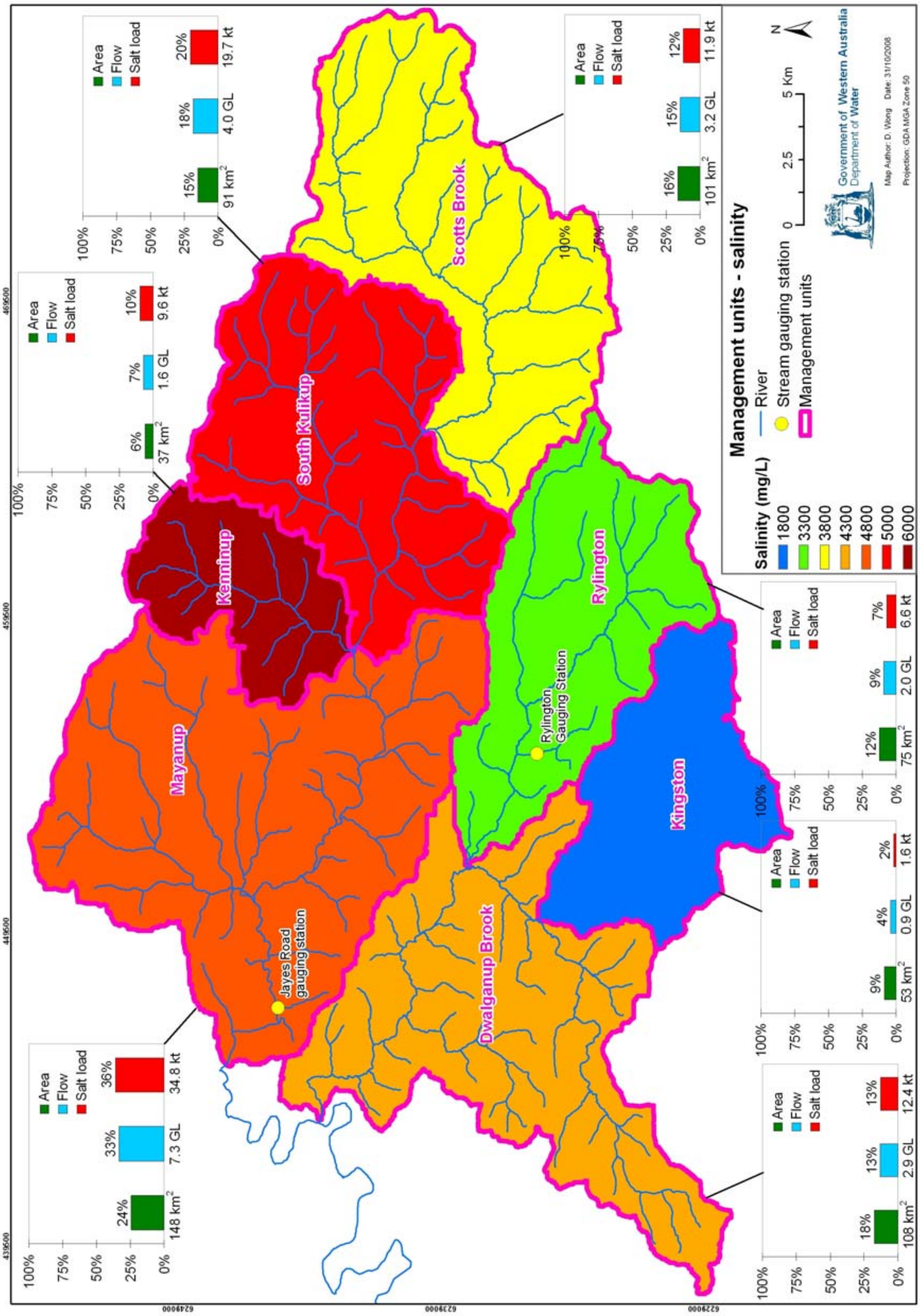

Figure 24 Relative contributions of management units with respect to flows, salt loads and salinity in 2007

5 Catchment management scenarios

Fifteen catchment management scenarios were modelled to 2092, representing three repeats of the rainfall record. Results have been extracted for the end of 2030 and 2060. The wide range of scenarios was selected to gauge the responsiveness of the catchment with respect to:

- Location of plantings (either ‘upper catchment’ – in the higher elevations of the catchment or ‘lower catchment’ – in the lower elevations of the catchment, or in areas or higher salt loads).
- Area of plantings
- Rooting depth of pastures
- Effects of combining scenarios
- Maximum possible outcomes

Fifteen management scenarios were modelled and five are reported in detail in this section to provide a sound understanding of salinity responses to changing land use. These scenarios were selected because their results (when compared against each other) provide the best information on the catchment response characteristics in terms of salt loads, flows and salinities. The remaining scenarios are summarised in Appendix F and demonstrate the catchment responses to various levels of plantation or perennial pastures establishment on previously cleared land (the percentages are how much of the total cleared area of 362 km^2 has been planted). The five scenarios are:

1. Base case – There is no further clearing or planting as at 2007, the ‘do nothing’ scenario.
2. 82% upland trees – Most (82%) of the cleared area is planted to trees, focusing on the upper parts of the catchment.
3. 59% strategic trees – Response units with the highest salt loads are planted with trees covering 59% of the cleared area.
4. 59% strategic trees and perennial pastures (3.5 m rooting depth) – As for ‘59% strategic trees’, with the remaining cleared area planted to perennials with 3.5 m rooting depth.
5. All cleared – All trees, native forest and plantations, are cleared.

Table 4 is a summary of the projected streamflow characteristics in 2030 and 2060 of Gnowergerup Brook (at the Jayes Road gauging station) and the Tweed River (at the catchment outlet) for scenarios 1–5. These values (although up to 4 significant figures) are from mathematical calculations using the LUCICAT model, and therefore do not represent exact values projected into the future. Moreover, future climate change has not been included in the modelling but the recent drier period 1979–2006 has been included. These values are a means of comparing the land-use scenarios to assist in decision making.

The other ten scenarios are described briefly below and reported in Appendix F.

6. 22% upland trees – 22% of the cleared area planted with trees focusing on the upper parts of the catchment.
7. 25% lowland trees – 25% of the cleared area planted with trees focusing on the lower parts of the catchment.
8. 55% upland trees – 55% of the cleared area planted with trees focusing on the upper parts of the catchment.
9. 55% lowland trees – 55% of the cleared area planted with trees focusing on the lower parts of the catchment.
10. 55% upland perennial pastures – 55% of the cleared area planted with perennials focusing on the upper parts of the catchment.
11. 55% lowland perennial pastures – 55% of the cleared area planted with perennials focusing on the lower parts of the catchment.
12. 59% strategic trees and perennial pastures (5 m rooting depth) – same as '59% strategic trees', with the remainder of the cleared area planted with perennials with a rooting depth of 5 m.
13. 88% lowland trees – 88% of the cleared area planted with trees focusing on the lower parts of the catchment.
14. 100% trees – The entire cleared area planted to trees.
15. 100% native vegetation – The entire cleared area planted to native vegetation.

Scenario 1 — 'Base case' ('do nothing')

The 'base case' scenario is the modelled projected salt-load, streamflows and salinities of the Tweed/Gnowergerup catchments using the 2007 land use data. It is also referred to as the 'do nothing' scenario and is the experimental 'control' against which the effects of all other management scenarios will be compared. In this scenario, it is assumed that nothing is done in the catchments; that is no further clearing or planting occurs from 2007 onwards.

Projected salinity will drop from the current flow-weighted mean of 5381 mg/L TDS (based on flow-weighted data collected 1999–2006) to 4636 mg/L by 2030 and 4613 mg/L by 2060 at the Jayes Road gauging station (Fig. 1). Salinity in the Tweed River catchment is projected to drop from 4341 mg/L to 3150 mg/L by 2030, and 3011 mg/L TDS by 2060.

Table 4 Impacts of selected management scenarios

Scenario	Salinity (mg/L)				Streamflow (GL)				Salt load (kt)			
	2030		2060		2030		2060		2030		2060	
	Tweed River	Gnowergerup Brook	Tweed River	Gnowergerup Brook	Tweed River	Gnowergerup Brook	Tweed River	Gnowergerup Brook	Tweed River	Gnowergerup Brook	Tweed River	Gnowergerup Brook
1. Base case	3150	4636	3011	4613	5.2	14.4	5.0	14.0	16.3	66.7	15.1	64.3
2. 82% upland trees	2260	2635	2140	2469	2.7	5.4	2.7	5.2	6.1	14.3	5.7	12.8
3. 59% strategic trees	1861	2154	1781	2128	3.6	5.8	3.5	5.5	6.8	12.5	6.2	11.7
4. 59% strategic plantings & remainder perennials (3.5 m)	641	1039	543	738	2.2	3.9	2.1	3.6	1.4	4.1	1.1	2.6
5. All cleared	3705	4998	5334	6135	11.4	20.6	14.3	22.6	42.4	103.0	76.4	138.9

In the ‘base case’ scenario response unit salt loads, salinities and flows generally decline with time (Figs 25–30).

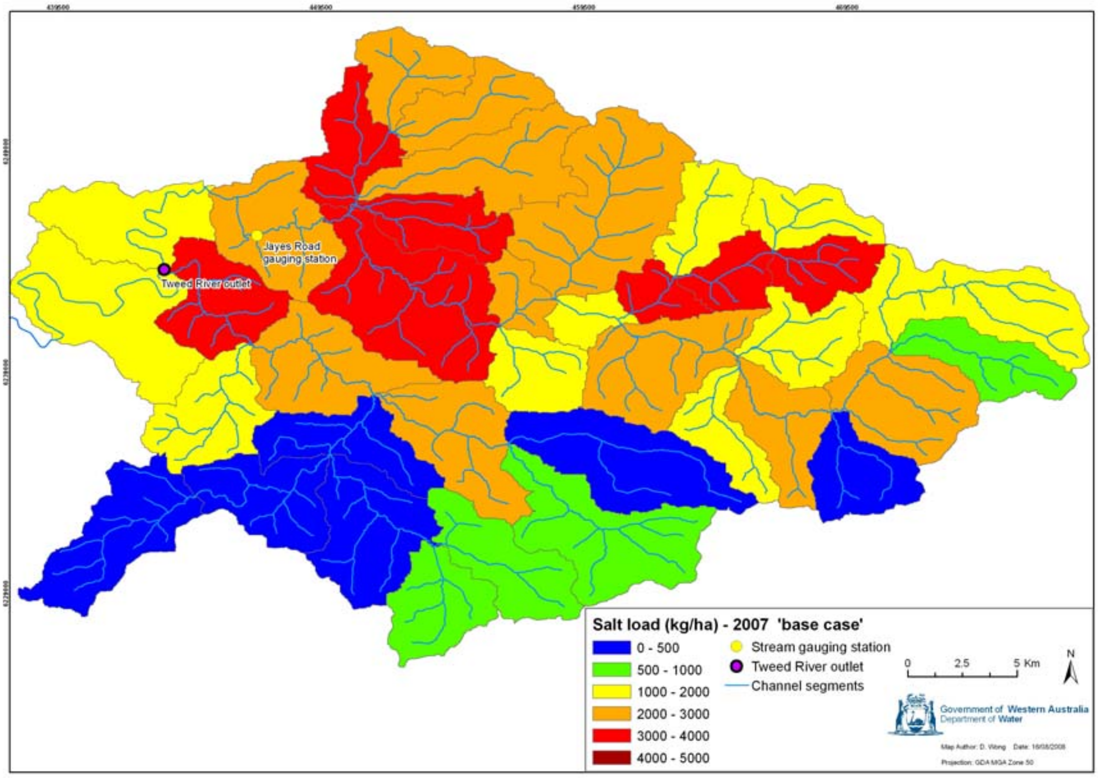

Figure 25 Salt loads of response units in 2007 – 'base case'

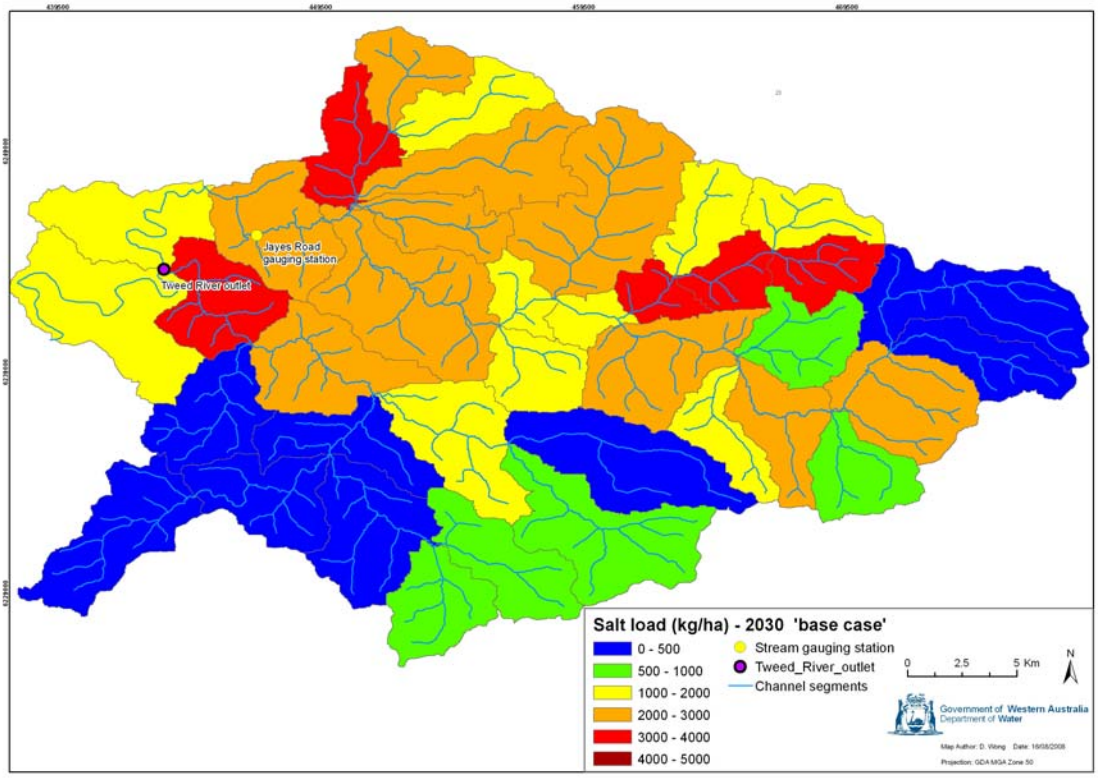

Figure 26 Salt loads of response units in 2030 – 'base case'

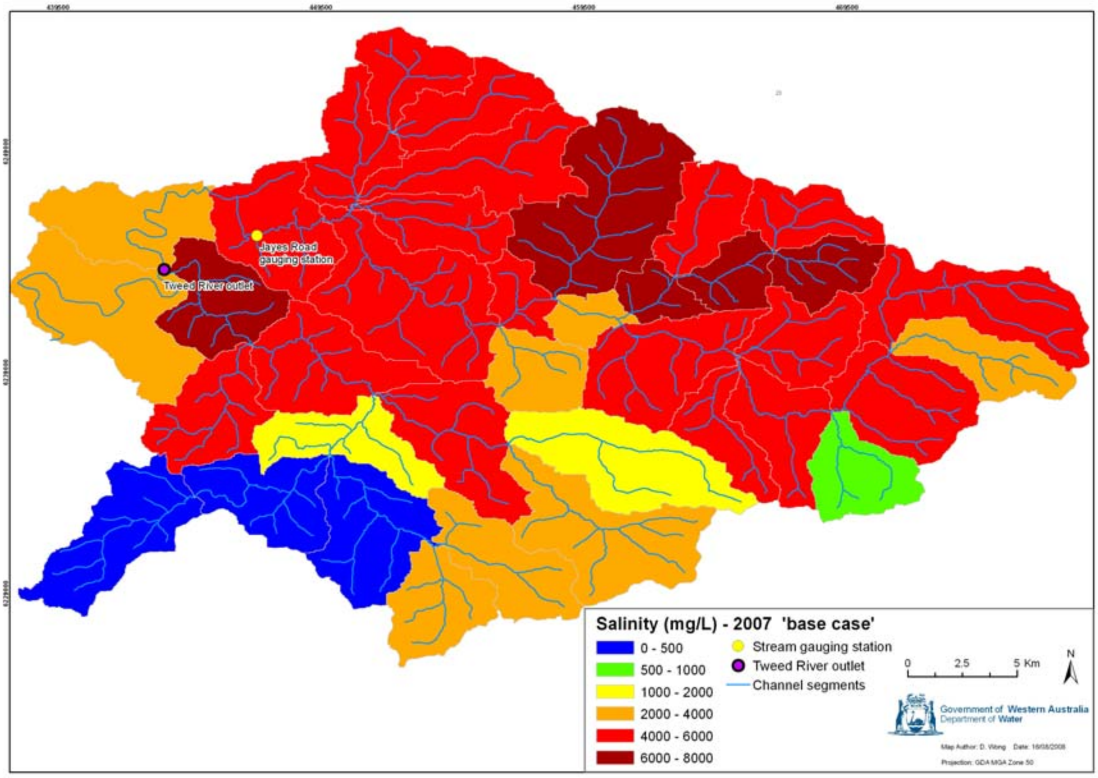

Figure 27 Salinity of response units in 2007 – 'base case'

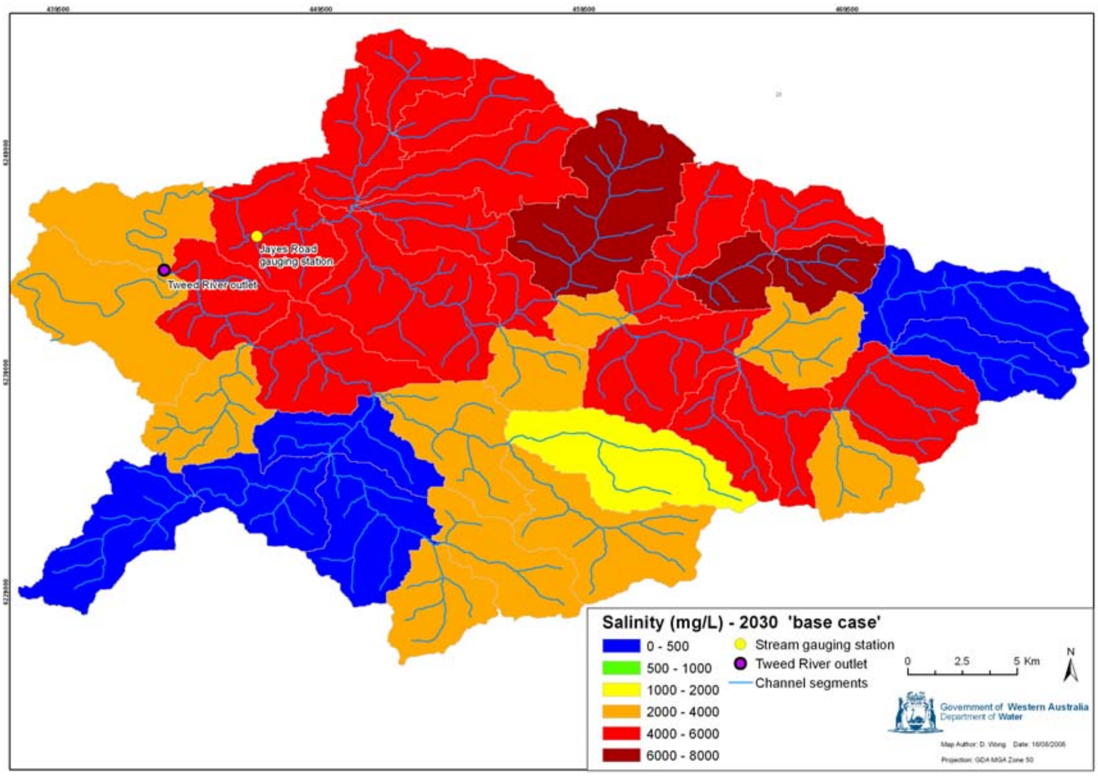

Figure 28 Salinity of response units in 2030 – 'base case'

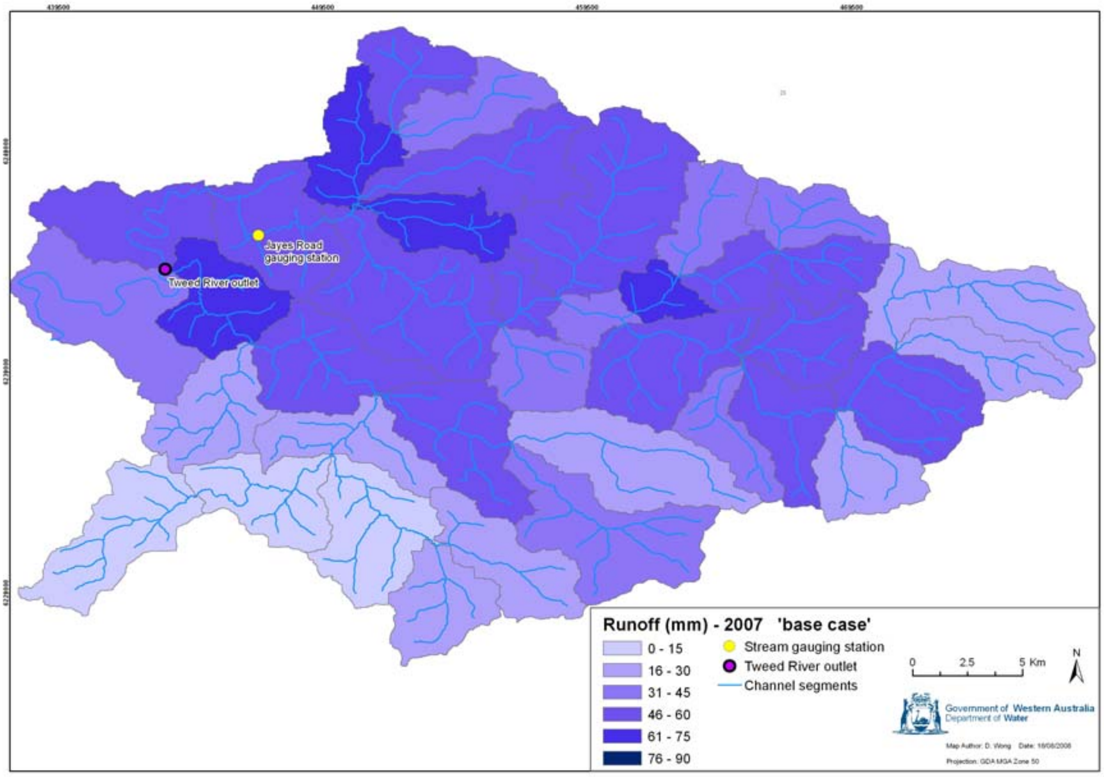

Figure 29 Runoff for response units in 2007 – 'base case'

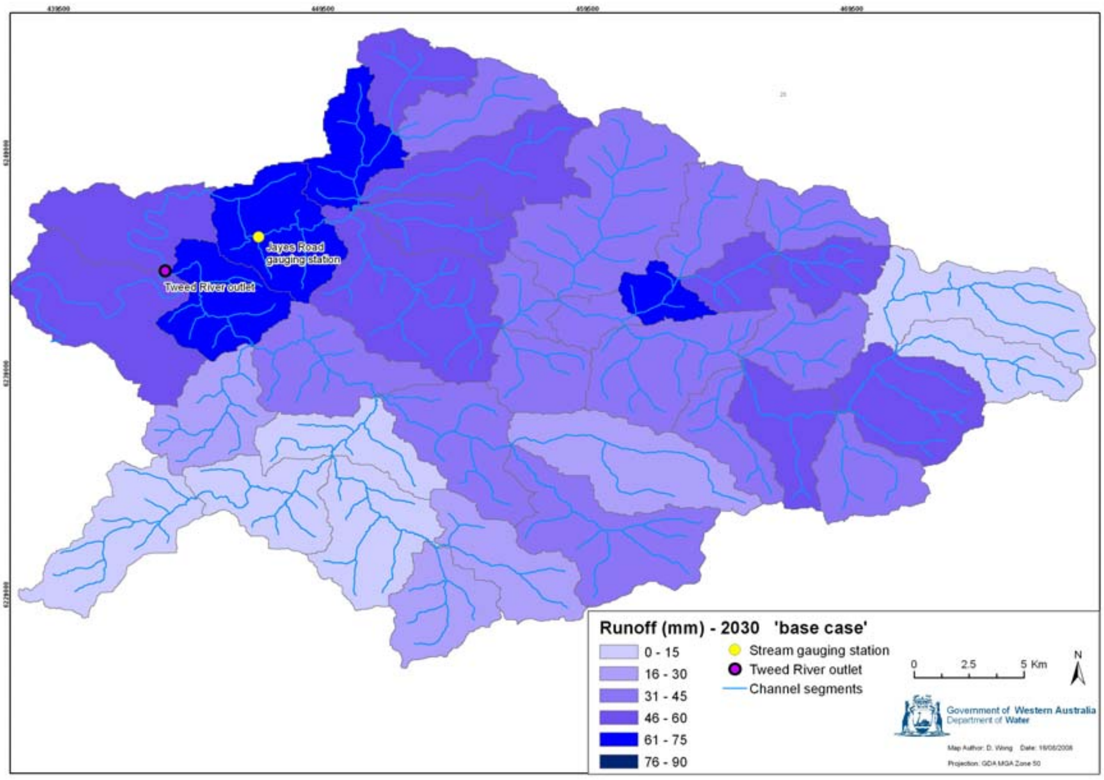

Figure 30 Runoff for response units in 2030 – 'base case'

Scenario 2 — 82% upland trees

Eighty-two percent of the cleared land is planted with trees in 2008 focusing on the upper catchment (Fig. 31). The cleared area of the upper responses units was aggregated until the desired area for plantations was reached (the initial scenario was to plant 80% of the cleared area). 100% of the cleared area in the responses units were planted to reach the target, resulting in 298 km^2 of plantations being modelled.

Projected mean salinities for the Tweed River and Gnowergerup Brook catchments will be reduced to 2260 mg/L and 2635 mg/L TDS respectively by 2030.

Reductions in catchment salt loads and salinities in all 'replanted' response units can be seen by comparing the salt loads (Fig. 26 with Fig. 32) and salinities (Fig. 28 with Fig. 33) of the 'base case' scenario with this scenario. Significant salt loads are still carried from the lower catchment area (Fig. 32).

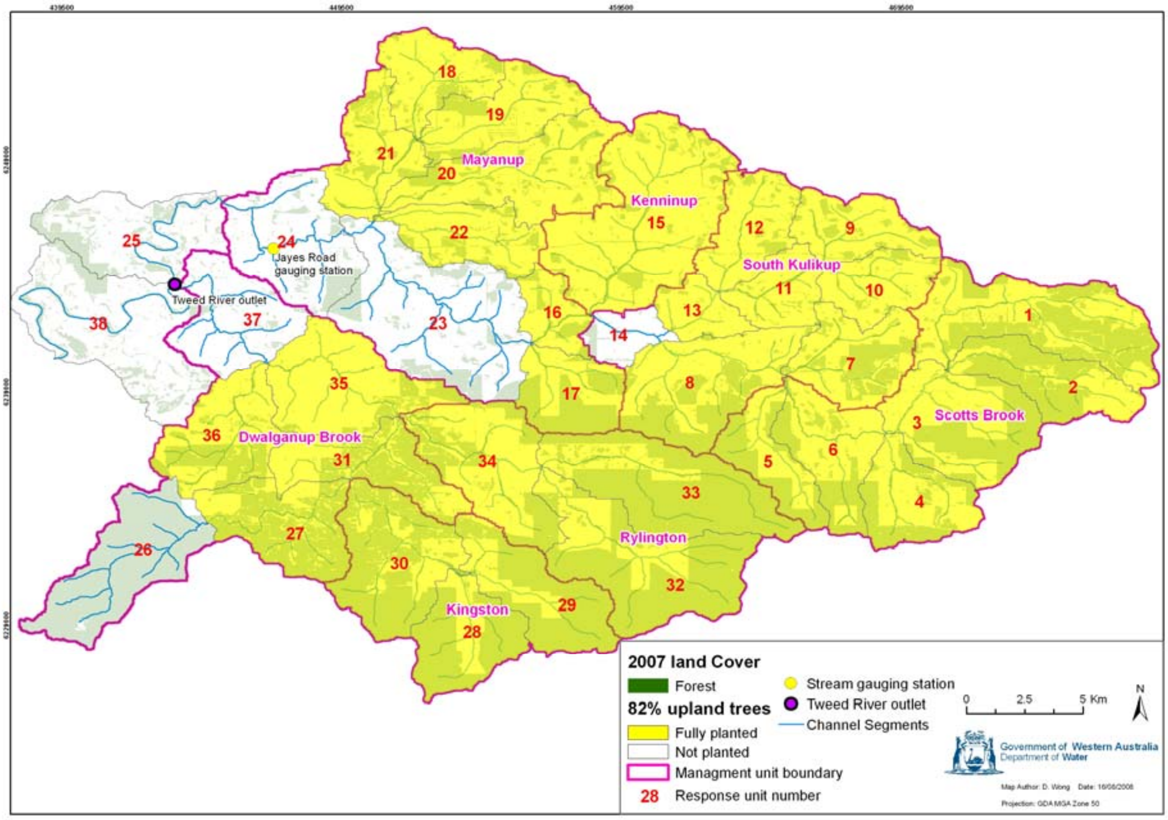

Figure 31 Response units selected for planting '82% upland trees'

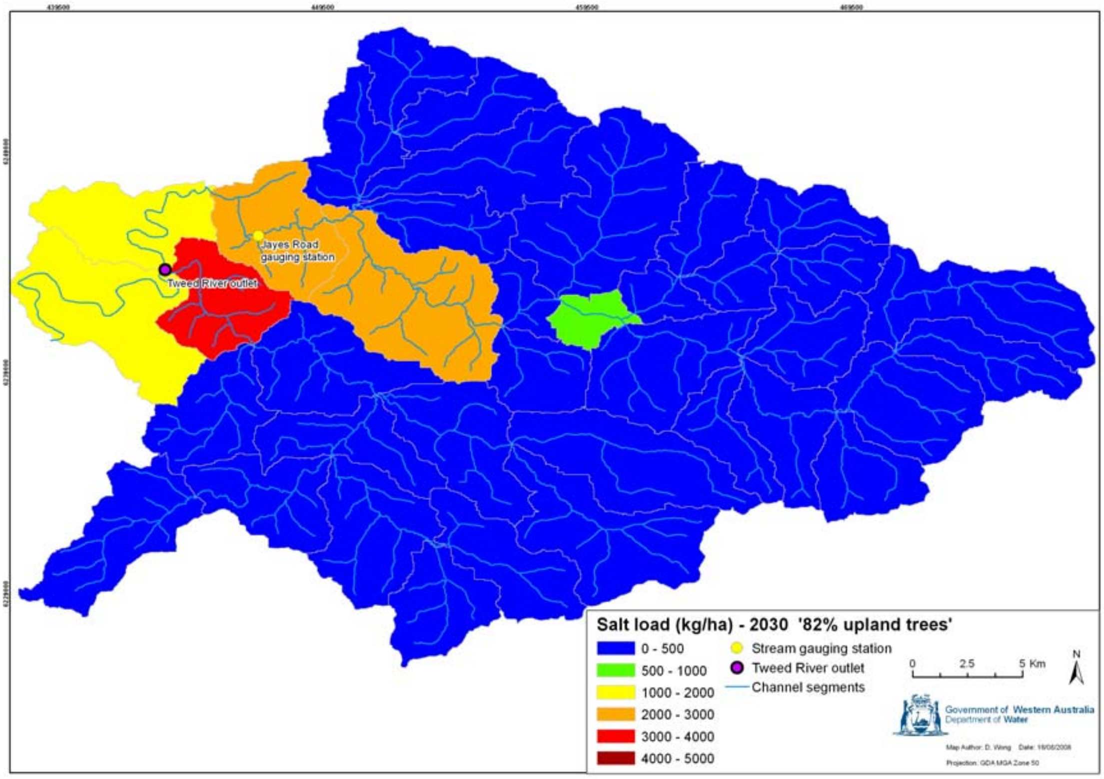

Figure 32 Salt loads of response units in 2030 – '82% upland trees'

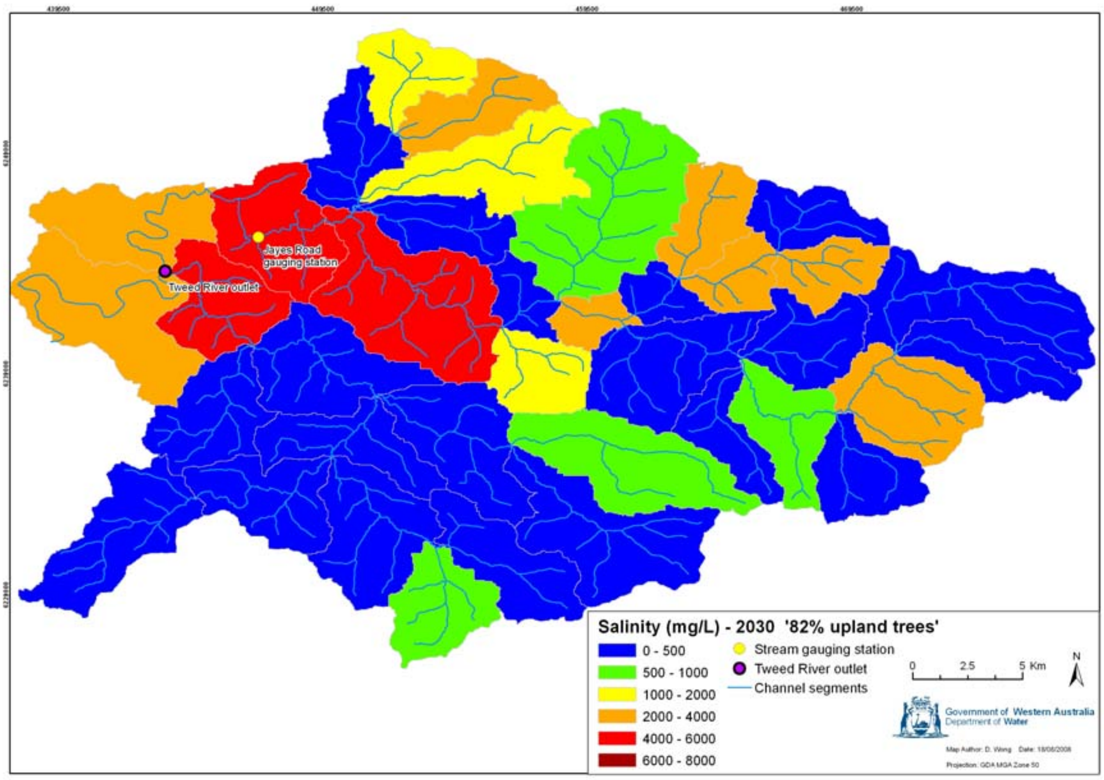

Figure 33 Salinity of response units in 2030 – '82% upland trees'

Scenario 3 — 59% strategic trees

It was considered necessary to analyse the salinity levels if the response units releasing the highest salt loads per hectare were planted. So response units with salt loads greater than 2000 kg/ha were selected for 'planting' with trees and response units with salt loads smaller than 2000 kg/ha were not planted (Fig. 34). This equated to 59% of the cleared area getting 'plantations'.

In 2030, projected salinities in the Tweed River and Gnowergerup Brook would be reduced to 1861 mg/L and 2154 mg/L respectively, representing salinity reductions of 1289 mg/L and 2482 mg/L TDS respectively compared to the 'base case' scenario.

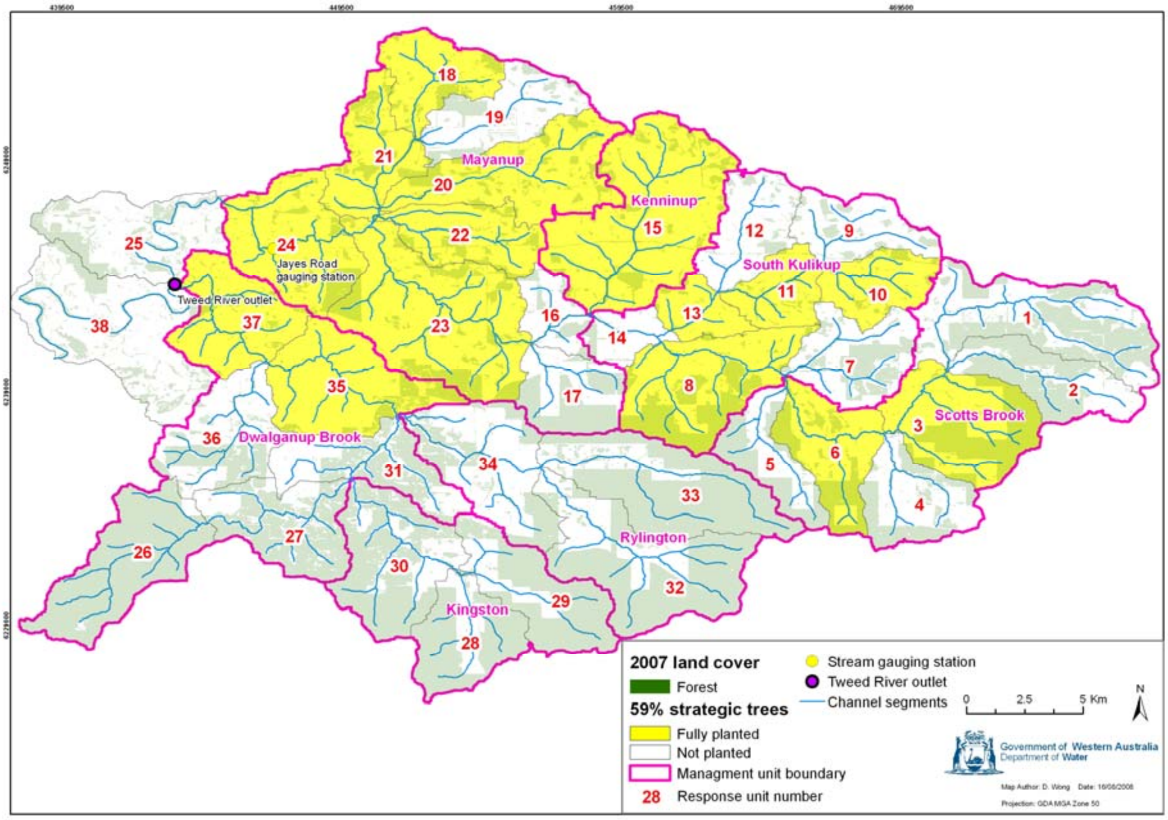

Figure 34 Response units selected for planting in '59% strategic trees'

The predicted salt loads, salinities and flows for the response units in 2030 are shown in Figures 35, 36, 37 respectively.

When response units (numbers 10, 11, 13, 21 and 37) with high salt loads (above 3000 kg/ha) were planted with trees, salt loads were reduced to less than 500 kg/ha (Fig. 35). There is also a reduction in response unit salinity, which can be seen by comparing the predicted salinity in 2030 (Fig. 36) to the 'base case' (Fig. 28).

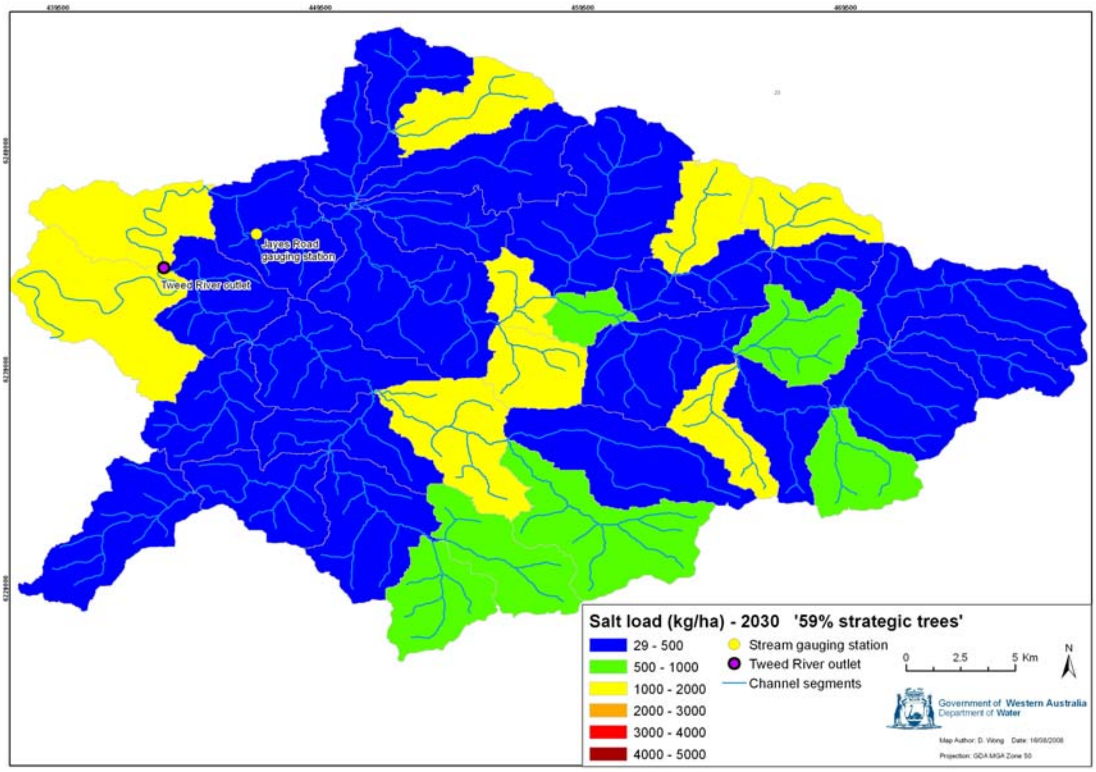

Figure 35 Salt loads of response units in 2030 – '59% strategic trees'

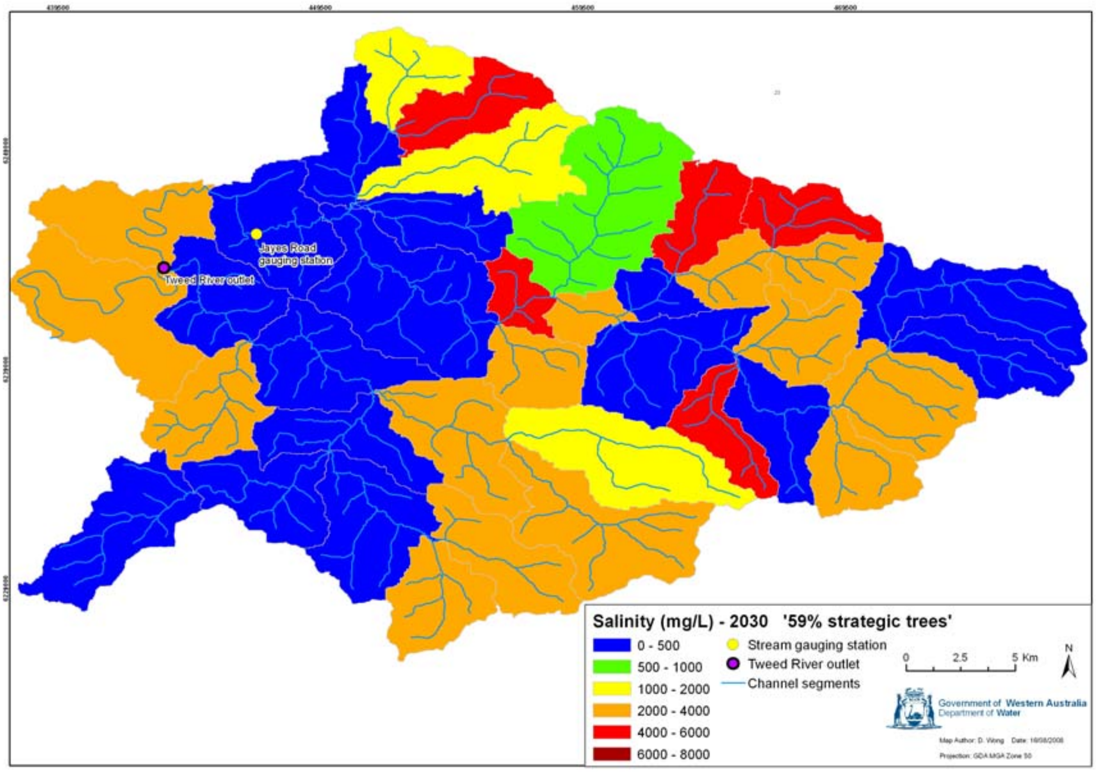

Figure 36 Salinity of response units in 2030 – '59% strategic trees'

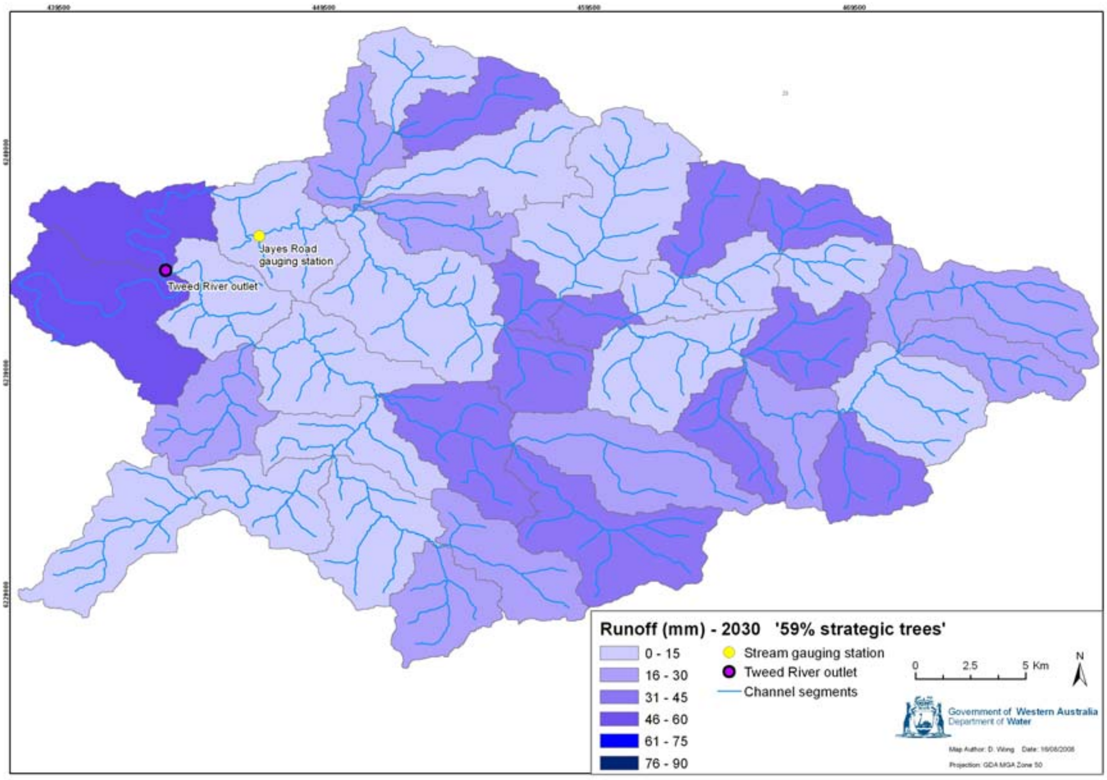

Figure 37 Runoff for response units in 2030 – '59% strategic trees'

Scenario 4 — 59% strategic trees and the remainder perennial pastures

The response units, as in the '59% strategic trees' scenario, are 'planted' with trees; with the rest of the cleared area 'planted' with perennial pastures with a rooting depth of 3.5 m.

By 2030, mean salinities in the Tweed River and Gnowergerup Brook are expected to fall to 641 mg/L and 1039 mg/L TDS respectively (Table 4) with further reductions expected by 2060 to means of 543 mg/L and 738 mg/L respectively (Table 4). These are reductions of 2468 mg/L (Tweed River) and 3875 mg/L (Gnowergerup Brook) compared with the 'base case' scenario in 2060.

Scenario 5 — All cleared

All existing vegetation is assumed to be 'cleared' in 2008 with both catchments having only annual pastures. The salinities of the Tweed River and Gnowergerup Brook do not increase significantly until after 2030 (Fig. 38). The mean projected salinity in 2030 at Jayes Road is 4998 mg/L and continues to increase to 6135 mg/L by 2060. Salinity in the Tweed is 3705 mg/L in 2030 and increases substantially to 5334 mg/L by 2060 (Table 4).

Salt loads are projected to increase significantly: the annual load from the Tweed River is 39.2 kt by 2030, more than twice the 'base case' (16.3 kt) and for Gnowergerup Brook, 97.9 kt compared with 66.7 kt for the 'base case' (Fig. 40).

The annual salt loads are projected to keep increasing until at least 2060 where averages of 76.4 kt (Tweed) and 138.9 kt (Gnowergerup) are exported annually. These are about five times the projected 'base case' annual salt load for the Tweed River (15.1 kt), and more than twice that for Gnowergerup Brook (64.3 kt).

Annual streamflows are also projected to increase, to be 11.4 GL and 20.6 GL for the Tweed River and Gnowergerup Brook respectively by 2030 (Table 4; Fig. 41).

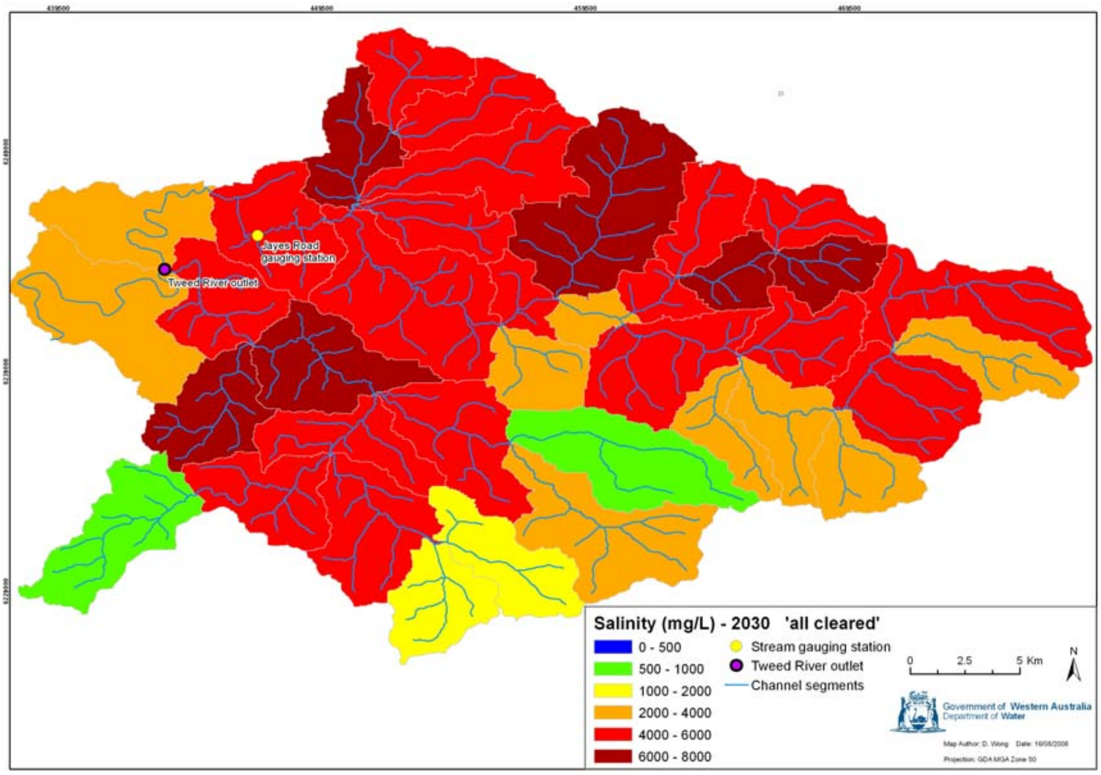

Figure 38 Salinity of response units in 2030 – 'all cleared'

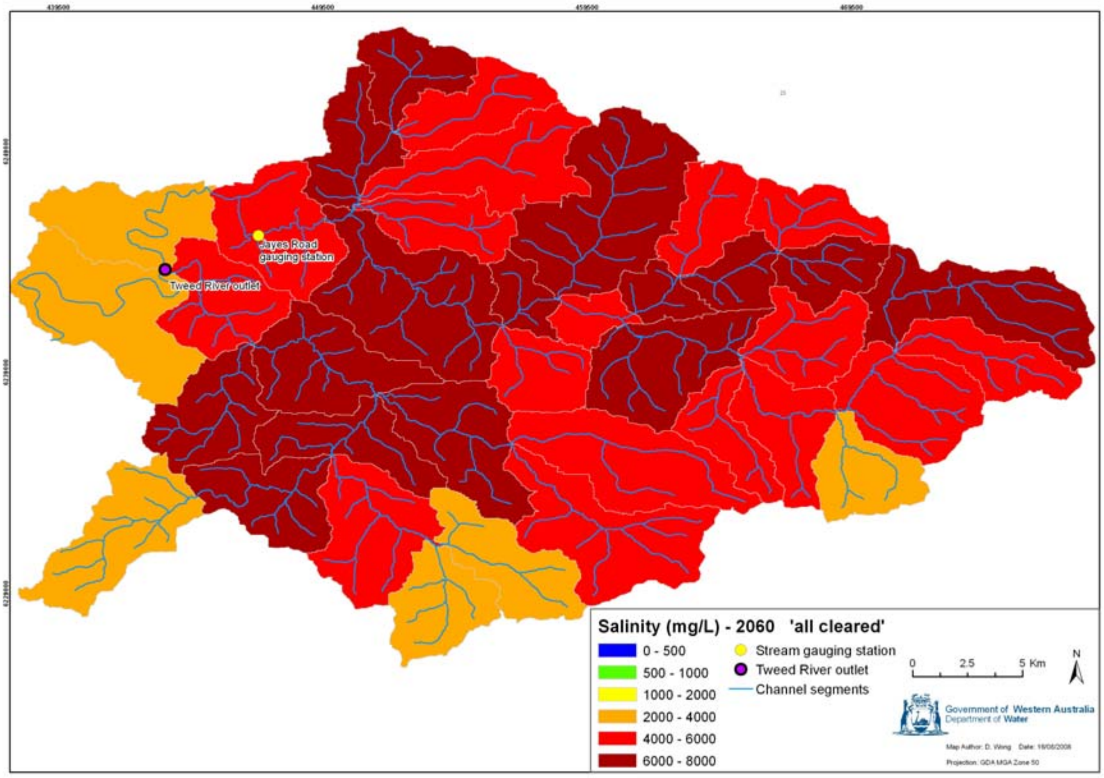

Figure 39 Salinity of response units in 2060 – 'all cleared'

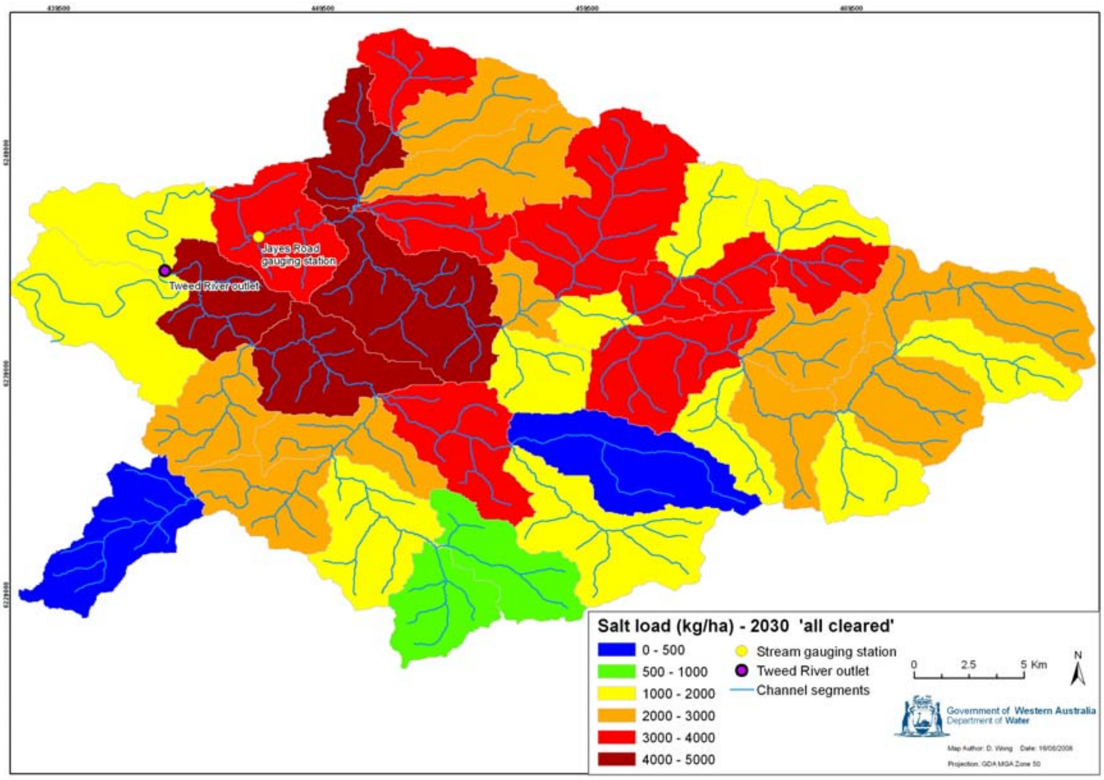

Figure 40 Salt load of response units in 2030 – 'all cleared'

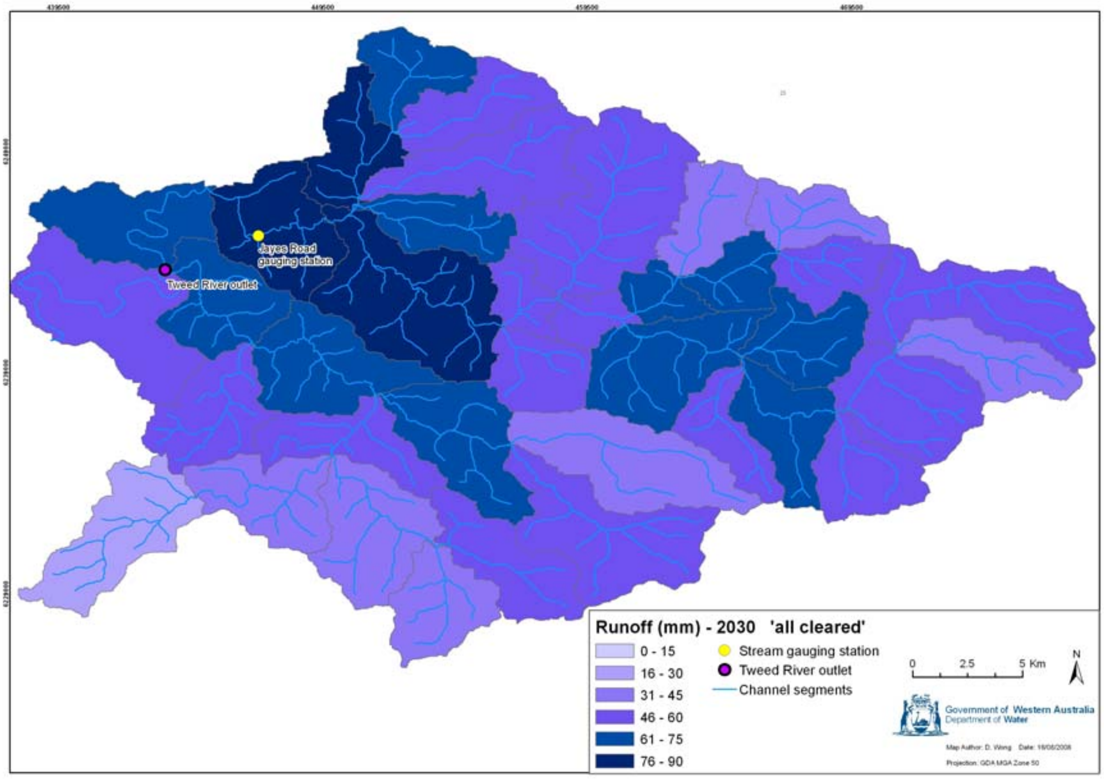

Figure 41 Flow of response units in 2030 – 'all cleared'

Scenarios 6 to 15

The greater the cleared area replanted, the smaller the salt loads, flows and salinities for the lowland and upland trees scenarios. The smallest salt loads and flows came from the '100% trees' and '100% native vegetation' scenarios, where there were projected salinities of less than 600 mg/L in 2030 (Appendix F).

The upland and lowland tree plantings of 22–55% of the cleared catchment area both reduce salt loads and salinities. However, for Gnowergerup Brook, salinities only go down to about 3000 mg/L. For the Tweed River the '55% lowland trees' scenario produced the lowest salinity of 626 mg/L (Appendix F).

Lowland plantings resulted in lower salinities than upland plantings where similar proportions of the cleared area were planted with trees ('22% upland trees' compared against '25% lowland trees'; and '55% upland trees' compared with '55% lowland trees') (Appendix F).

6 Discussion

The impacts of land-use options on catchment salinity depend on the locations and area of plantings, the rooting depth of pastures, the combination of options and time.

Establishing plantations in areas that produce the most salt is the most effective, so 59% strategic plantations have similar salinity outcomes to 82% upland trees at the Jayes Road gauging station (Fig. 42).

Planting deep-rooted vegetation across the entire catchment can significantly reduce salinity. Where trees are mixed with perennial pastures produce the best salinity figures of scenarios 1–5 (Fig. 42). The '59% strategic trees' scenario combined with perennials reduces the flow-weighted mean salinity at Jayes Road from 4738 to 626 mg/L in 2030. Salinity drops further and potable salinity (below 500 mg/L) is achieved by around 2037. Only the 'all planted' scenario had projected salinities below 500 mg/L by 2030.

The current vegetation cover is important in preventing salinity and salt load increases and the full impacts of clearing on salinity take decades to be fully manifested. This is evident when the 'base case' is compared with the 'all cleared' scenario (Figs 43 & 44). If all the existing forest had been cleared in 2008, annual average catchment salinities of the Tweed and Gnowergerup would be 555 and 362 mg/L respectively higher than the 'base case' by 2030 (Table 4) but by 2060 would be 2323 and 1522 mg/L above the projected 'base cases' respectively (Table 4).

Although all the revegetation scenarios reduce salinities and salt loads, they also reduce streamflows. The 'all cleared' scenario has the highest streamflow (Table 4) but also the highest salinities and salt loads. Conversely, the '100% native vegetation' scenario produced the lowest projected streamflows but the freshest water (Appendix F).

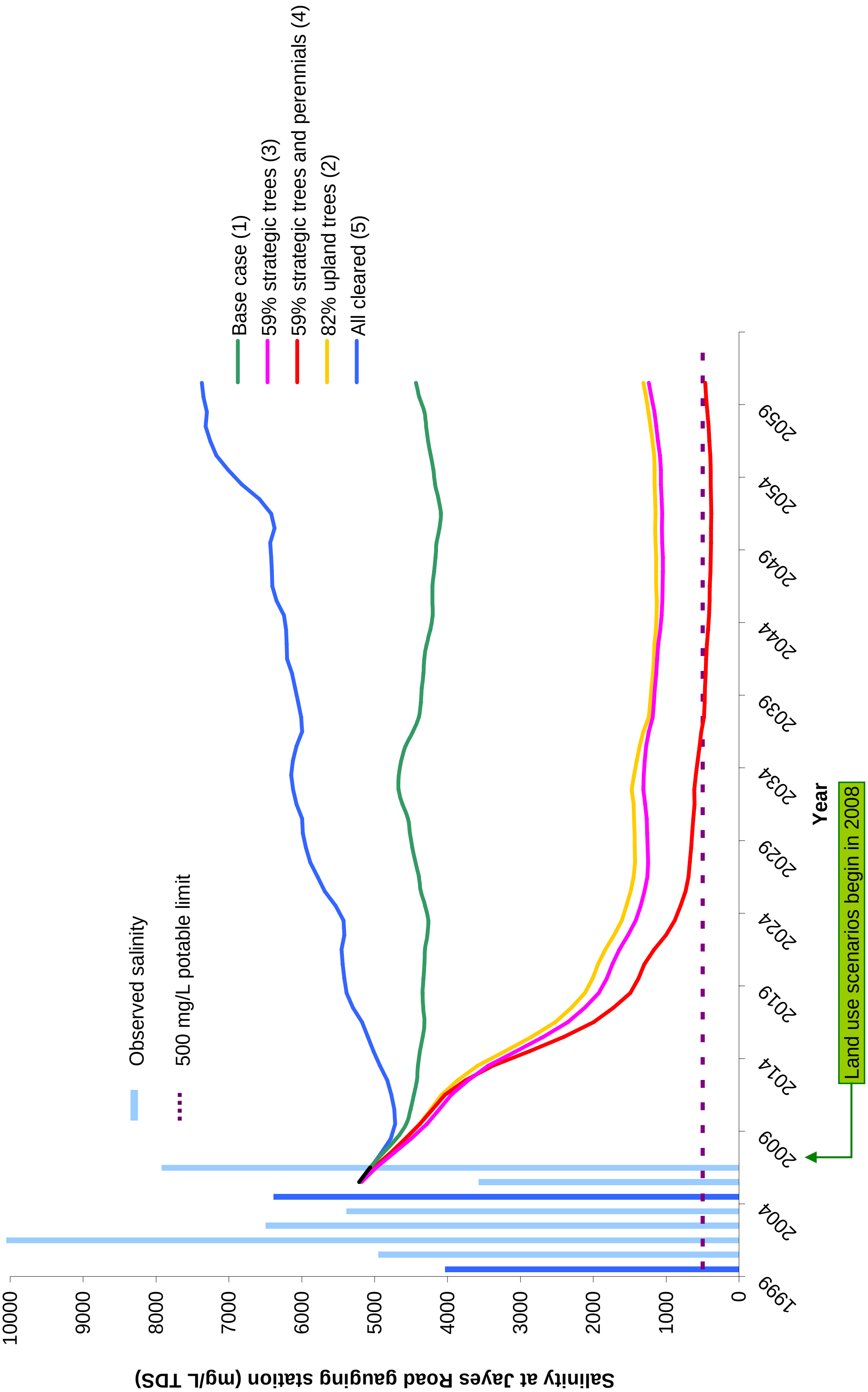

Figure 42 Projected salinities at mean flow at the *Jayes Road gauging station for selected management scenarios*

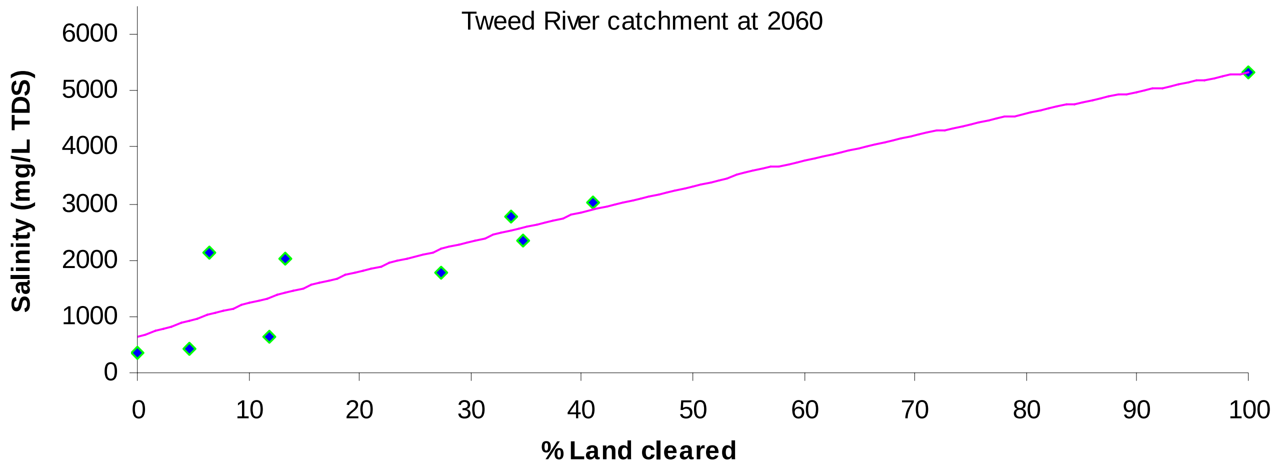

Figure 43 Relationship between salinity and the proportion of cleared land in the Tweed River catchment

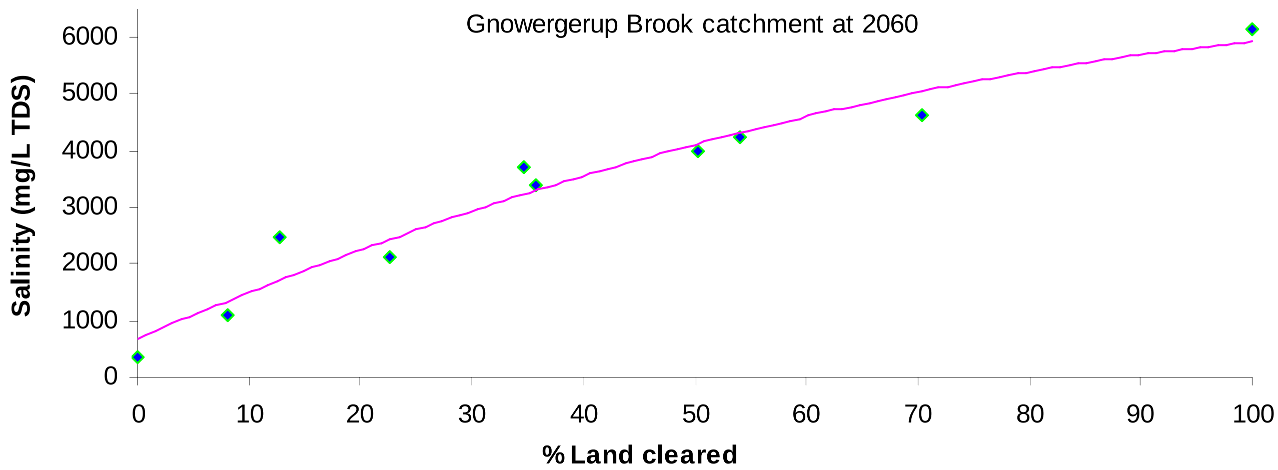

Figure 44 Relationship between salinity and the proportion of cleared land in the Gnowergerup Brook catchment

The streamflow (Tweed River in 2030) in the ‘all cleared’ scenario is 11.4 GL compared to 5.2 GL for the ‘base case’ and 2.2 GL for the ‘59% strategic plantings & remainder perennials (3.5 m)’ scenarios, with salinities for these scenarios 3705, 3150 and 641 mg/L respectively. As expected, catchment salinity reduction is inversely proportional to streamflow as plants lose more water by evapotranspiration leaving less water as runoff into streams.

7 Conclusions

- The salinities of the Tweed River and Gnowergerup Brook are not expected to increase significantly provided that there is no further clearing.
- The salinities of the Tweed River and Gnowergerup Brook can be reduced to annual means of 543 and 738 mg/L respectively by planting 59% of the cleared area to trees, and the remainder to deep-rooted perennial pastures. When taking into account flow-weighted mean data, stream salinity may be reduced to less than 500 mg/L by around 2037.
- Achieving an average annual salinity reduction to around 500 mg/L can be achieved by targeting salinity mitigation actions to areas producing the most salt; namely, the heavily cleared areas in the lower catchments, with the remaining cleared areas planted with deep-rooted perennials.
- The full benefits of revegetation may not be achieved until around 35–40 years after planting.
- Returning the catchments to native forest or planting with plantation timber will return streams to ‘fresh’ water quality.
- Revegetation scenarios involve a compromise between salinity reduction and streamflow reduction.

8 A way forward

This study focuses on conceptual salinity reduction options – to understand the extent of the land-use changes needed to reach a salinity target.

Further work is needed on understanding the implications of the options from economic, environmental and social perspectives. Further work would be needed to ascertain the suitability of the land identified for commercial timber plantations and perennial pastures.

Glossary

Channel network	A network of lines, derived via GIS processing, used in LUCICAT modelling. Derivation of a channel network is based on DEMs and its structure mimics the natural hydrological stream network.
DEM	Digital elevation model. The representation of continuous elevation values over a topographic surface by a regular array of z-values, referenced to a common datum. DEMs are typically used to represent terrain relief (ESRI 2006)
Duplex soil	Soils with a sharp texture contrast between the A and B horizons. A duplex soil is often characterised by a sandy or loamy surface horizon with a sharp to clear boundary to a clay subsoil (DPI 2008).
Flow (mm)	Flow expressed as millimetres of catchment runoff; derived by calculating the volume of water in a Response Unit and dividing that amount by its area
Hectare (ha)	10 000 square metres. 100 ha = 1 square kilometre.
LUCICAT	Acronym for Land Use Change Incorporated Catchment Model.
m AHD	Australian Height Datum. Height in metres above Mean Sea Level.
Management unit	Land areas defined by the local community predominantly based on surface water drainage with some variations to account for social and soil type boundaries.
Node	A point designated at the beginning and the junctions of a channel network that is used in LUCICAT.
Response unit	The smallest hydrological unit that is used by the LUCICAT model. It consists of one outlet only, but may have more than one inlet. It is derived via GIS processing and is a key component of the LUCICAT model.
Salinity	The concentration of dissolved salts in water. It is commonly measured in mg/L Total dissolved salts (TDS).
Salt load (kg/ha)	Salt expressed as kilograms per hectare; derived by calculating the total salt in a Response Unit and divided that amount by its area.

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Appendix A - Description of vegetation complexes

Vegetation complex	Description
Bevan 2 (BE2)	Open forest to woodland of *Eucalyptus marginata subsp. marginata* with some *Corymbia calophylla* on lateritic uplands in humid and subhumid zones.
Bevan 3 (BE3)	Woodland of *Eucalyptus marginata subsp. marginata* with some *Eucalyptus wandoo* on low rises in subhumid and semiarid zones.
Bevan (BEs)	Open forest to woodland of *Eucalyptus marginata subsp. marginata-Corymbia calophylla* on uplands in the subhumid zone.
Brockman (BR)	Woodland of *Corymbia calophylla – Eucalyptus wandoo* over *Hakea prostrata* and *Acacia saligna* on valley slopes ranging to sedgelands and heaths on valley floors in the semi-arid zone.
Carbunup (CB)	Woodland of *Eucalyptus marginata subsp. marginata – Corymbia calophylla* and low woodland of *Melaleuca preissiana – Banksia littoralis* on slopes in the sub-humid zone.
Catterick (CC2)	Open forest of *Corymbia calophylla – Eucalyptus marginata subsp. marginata* with some *Eucalyptus wandoo, Eucalyptus patens* and *Eucalyptus cornuta* on slopes and woodland of *Eucalyptus rudis – Melaleuca rhaphiophylla* on lower slopes in sub-humid and semi-arid zones.
Corbalup 2 (CL2)	Open forest of *Eucalyptus marginata subsp. marginata* with some *Corymbia calophylla* on low rises and low woodland of *Melaleuca preissiana – Banksia littoralis* on depressions in humid and sub-humid zones.
Collis 2 (CO2)	Open forest of *Eucalyptus marginata subsp. marginata – Corymbia calophylla – Banksia grandis* on low uplands, with some lithic complex associated with granite outcrops in humid and sub-humid zones.
Dalmore 1 (DM1)	Woodland of *Corymbia calophylla – Eucalyptus marginata subsp. marginata* with occasional *Eucalyptus wandoo* on uplands in the sub-humid zone.
Dalmore 2 (DM2)	Woodland of *Eucalyptus wandoo – Eucalyptus marginata subsp. marginata – Corymbia calophylla* on uplands in semi-arid and arid zones.
Gnowergerup (GW)	Woodland of *Eucalyptus rudis – Melaleuca rhaphiophylla*, tall shrublands of *Melaleuca viminea* and sedgelands of *Baumea spp*. on valley floors in the semi-arid zone.
Kulikup 2 (KU2)	Open forest of *Eucalyptus marginata subsp. marginata – Corymbia calophylla* with some *Eucalyptus wandoo* and occasional *Eucalyptus astringens* (near breakaways) over *Acacia microbotrya* on undulating uplands in the semi-arid zone.
Lukin 2 (LK2)	Woodland of *Eucalyptus wandoo* with some mixtures of *Eucalyptus marginata subsp. thalassica* and *Corymbia calophylla* on the valley slopes with occasional *Eucalyptus rudis* on valley floors in semi-arid and arid zones.
Newgalup 1 (NW1)	Woodland of *Corymbia calophylla* and *Eucalyptus marginata subsp. marginata* with some *Eucalyptus wandoo* on upper slopes in the sub-humid zone.
Newgalup 2 (NW2)	Woodland of *Eucalyptus wandoo* with some *Corymbia calophylla* and *Eucalyptus marginata subsp. marginata* over *Dryandra sessilis* on upper slopes in the semi-arid zone.
Newgalup 1 (NWf1)	Woodland of *Eucalyptus rudis – Eucalyptus patens* on footslopes on valley slopes in the sub-humid zone.
Newgalup 2 (NWf2)	Woodland of *Eucalyptus rudis – Eucalyptus patens* with occasional *Eucalyptus wandoo* on footslopes on valley slopes in the semi-arid zone.

Vegetation complex	Description
Newgalup 1 (NWg1)	Woodland of *Corymbia calophylla* – *Eucalyptus marginata subsp. marginata* on slopes, open heath on shallow soils near granites, open forest of *Eucalyptus rudis* – *Eucalyptus wandoo* on the valley floors in the sub-humid zone.
Newgalup 2 (NWg2)	Woodland of *Eucalyptus marginata subsp. marginata* – *Corymbia calophylla* on slopes, open heath on shallow soils near granites, open forest of *Eucalyptus rudis* – *Eucalyptus wandoo* on steeper slopes and valley floors in the semi-arid zone.
Sandalwood (SD)	Woodland of *Eucalyptus marginata subsp. marginata* with some *Corymbia calophylla* and *Eucalyptus wandoo* over *Hakea prostrata* and *Dryandra sessilis* on steeper uplands in the semi-arid zone.
Yornup (YR)	Mosaic of open woodland of *Eucalyptus marginata subsp. marginata* – *Corymbia calophylla*, open woodland of *Melaleuca cuticularis*, open woodland of *Melaleuca preissiana* – *Banksia littoralis* – *Banksia seminuda*, tall shrubland of *Myrtaceae spp*. and sedgelands on broad depressions in humid and sub-humid zones.

(From CALM 2005)

Appendix B - Description of geological types

Geological type	Age	Description
Ag	Archaean	Granitoid rock, porphyritic and even-grained; sub-surface generally weathered to clayey sand (indicated by lighter colour) or sandy clay
Ago	Archaean	Granitoid rock, porphyritic and even-grained; sub-surface generally weathered to clayey sand (indicated by lighter colour) or sandy clay (outcrop)
An	Archaean	Granitoid gneiss, migmatite and minor schist; sub-surface generally weathered to clay (indicated by lighter colour)
Ano	Archaean	Granitoid gneiss, foliated, minor migmatite, schist and amphibolite: sub-surface weathered to clay (outcrop)
Tgc	Tertiary - Cainozoic - Phanerozoic	Alluvial lacustrine and shallow marine deposits - clay and sand

Appendix C - Description of geological units

Code	Description
Age	Even-grained granite rocks - fine to coarse-grained granodiorite, adamellite and granite
Age/Blo	Overprint, indicating bedrock largely obscured by residual and colluvial deposits on Age
Agg	Leucocratic adamellite, fine to coarse-grained with abundant pegmatite
Agg/Blo	Overprint, indicating bedrock largely obscured by residual and colluvial deposits, on Agg
Agv	Fine to medium-grained adamellite and granite with scattered microcline megacrysts
Agv/Blo	Overprint, indicating bedrock largely obscured by residual and colluvial deposits on Agv
Agze	Even-grained hornblende-ebaring quartz monzonite. Local range to alkali granite and syenite. Often recrystallized and lineated
Am	Migmatite - banded and nebulitic, often strongly contorted
Am/Blo	Overprint, indicating bedrock largely obscured by residual and colluvial deposits on Am
Ana	Augen gneiss, coarse-grained with microcline augen, strong cataclastic foliation
Ana/Blo	Overprint, indicating bedrock largely obscured by residual and colluvial deposits on Ana
Anb	Quartz-feldspar-biotite(-garnet) gneiss, generally well-banded. Includes blastomylonite along Darling Scarp
Anb/Blo	Overprint, indicating bedrock largely obscured by residual and colluvial deposits on Anb
Czc	Conglomerate - cobbles and boulders in sand or clay matrix, variably lateritized
Czl	Laterite - chiefly massive, but includes overlying pisolithic gravel and minor lateritized sand
Czs	Sand overlying laterite - yellow, white, grey or orange
Qra	Alluvium - clay, sand and loam
Qrc	Colluvium, including valley-fill deposits, variably lateritized and podsolized
Qrcs	Colluvium - sand, often associated with older drainage courses
Qrw	Swamp and lacustrine deposits - peat, peaty sand and clay
Tg	Old alluvial deposits, strongly lateritized in part (includes Greenbushes Formation). Conglomerate, sand and clay.

(Extracted from GSWA 2006)

Appendix D — Description of soil subsystems

Map of soil subsystems for Table 5 (derived from DAFWA 2007)

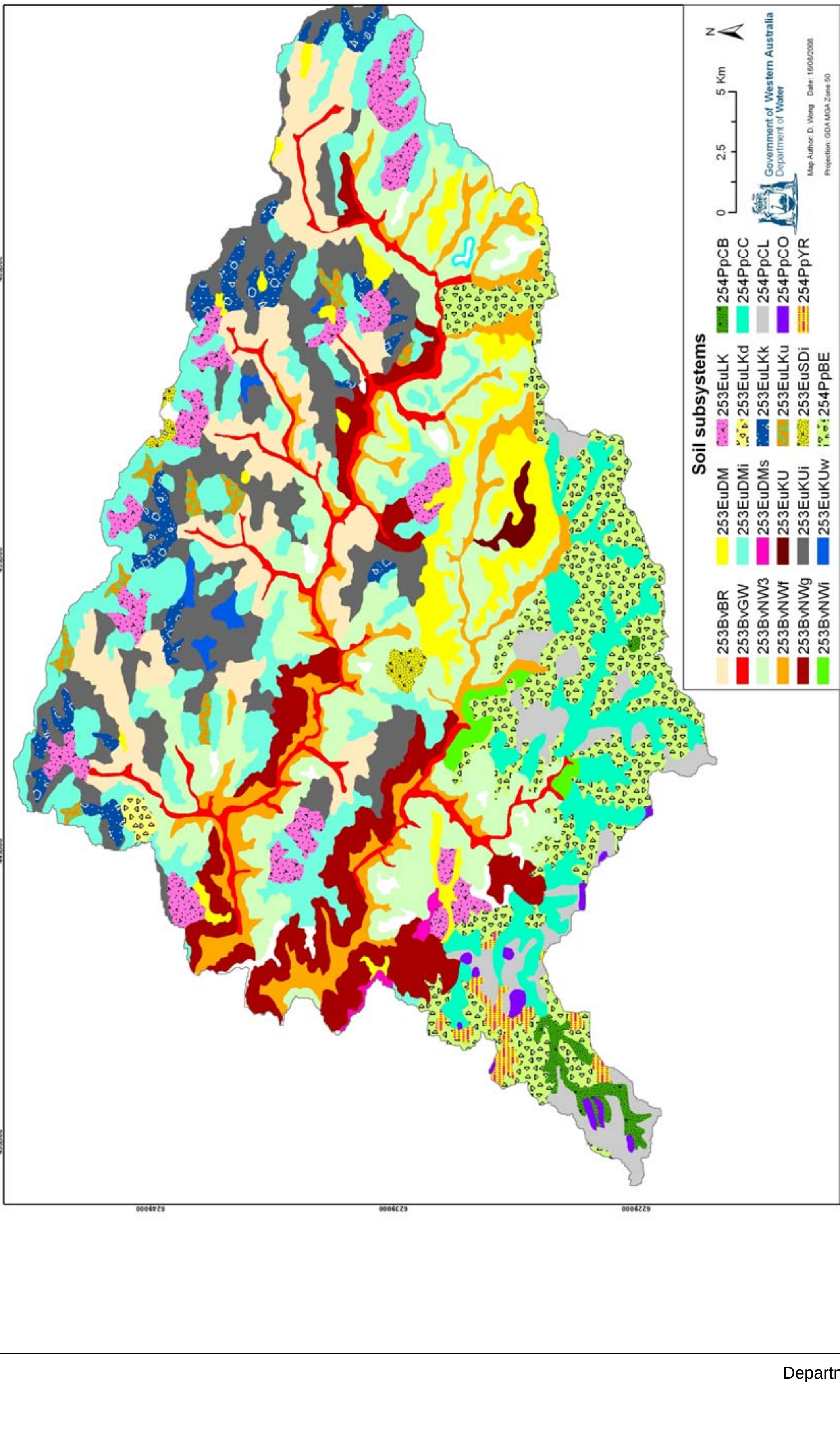

Table 5 Description of soil subsystems

Unit	Unit name	Topography	Soil description
253BvBR	Boree Subsystem	Shallow (5–25 m) major valleys with gentle slopes (3–10%). Soils are sands and sandy gravels.	Duplex sandy gravels, loamy gravels, grey deep sandy duplexes and brown deep loamy duplexes
253BvGW	Gnowergerup Subsystem	Poorly drained narrow floodplains.	Saline wet soils, wet and semi-wet soils and grey deep sandy duplexes
253BvNW3	Newlgalup low slopes Phase	Moderately incised valleys. Relief 30–50 m, slopes 5–20%. Soil parent material is granite and lateritic colluvium.	Loamy gravel, duplex sandy gravels, grey deep sandy duplexes, brown deep loamy duplexes and brown loamy earths
253BvNWf	Newlgalup footslopes Phase	Gentle slopes running in to the valley floor. Relief 5–10 m, slopes 3–10%. Soils are often poorly drained. Soils are loamy gravels, sandy gravels, sands and loams.	Loamy gravels, duplex sandy gravels, brown deep loamy duplexes, semi-wet soils and grey deep sandy duplexes
253BvNWg	Newlgalup granitic slopes Phase	Relief 30–50 m, slopes 5–20%. Soil parent material is granite and gneiss. Soils are deep loamy duplex soils, deep sandy duplex soils, loamy and sandy gravels, with some loamy earths and shallow loamy duplex soil	Loamy gravels, brown deep loamy duplexes, brown loamy earths, friable red-brown loamy earths and yellow/brown deep sandy duplexes
253BvNWi	Newlgalup ironstone gravel slopes Phase	Relief 30–50 m, slopes 5–15%. Soil parent material is lateritic colluvium over granite. Soils are loamy gravels, moderately deep sandy gravels with some shallow gravels, sandy duplex soils and loamy earths.	Duplex sandy gravels, loamy gravels and grey deep sandy duplexes
253EuDM	Dalmore Subsystem	Undulating ridges and hill crests on laterite and granite. Relief 5–20 m, slopes 5–15%. Soils are gravels, loamy duplex and sandy duplex soils.	Duplex sandy gravels, loamy gravels, yellow/brown deep sandy duplexes and brown deep loamy duplexes
253EuDMi	Dalmore ironstone gravel ridges Phase	Soil parent material is laterite. Soils are gravels, and sands.	Duplex sandy gravels and loamy gravels
253EuDMs	Dalmore sandy ridges Phase	Soil parent material is Kirup Conglomerate. Soils are sandy gravels, and sands.	Duplex sandy gravels, gravelly pale deep sands and grey deep sandy duplexes
253EuKU	Kulikup Subsystem	Poorly drained flats and gently undulating terrain with circular lakes and swampy depressions. Soils are sandy and loamy gravels with some sandy earths and deep sands.	Duplex sandy gravels, loamy gravel and semi-wet soils
253EuKUi	Kulikup ironstone gravel flats Phase	Moderately well drained to poorly drained gravels.	Duplex sandy gravels, semi-wet soils and loamy gravels
253EuKUw	Kulikup wet flats Phase	Poorly drained depressions and swamps.	Wet soils,semi-wet soils and duplex sandy gravels

Unit	Unit name	Topography	Soil description
253EuLK	Lukin Subsystem	Shallow (5–40 m) minor valleys with swampy floors incised in to lateritic terrain. Soils are sandy and loamy gravels, loamy duplex soils and deep sands.	Duplex sandy gravels, loamy gravels, grey deep sandy duplexes, and saline and semi-wet soils
253EuLKd	Lukin downstream valleys Phase	Relief 20–40 m, slopes 5–20%. Soils are loamy earths and loamy duplex soils with some gravels and sands.	Loamy gravels, duplex sandy gravels, brown deep loamy duplexes and brown loamy earths
253EuLKk	Lukin shallow Kulikup Phase	Shallow valleys with gentle slopes incised in to Eocene sedimentary deposits. Relief 5–20 m, slopes 3–10%. Soils are gravels and sands.	Duplex sandy gravels, loamy gravels and wet, saline wet and semi-wet soils
253EuLKu	Lukin upstream valleys Phase	Relief 5–20 m, slopes 3–10%.	Duplex sandy gravels, loamy gravels, grey deep sandy duplexes and wet, saline wet and semi-wet soils
253EuSDi	Sandalwood ironstone gravel hills Phase	Lower to upper slopes and hillcrests. Duplex sandy gravels and loamy gravels with minor areas of shallow gravels.	Duplex sandy gravels and loamy gravels
254PpBE	Bevan Subsystem (Perup)	Broad, gently sloping (gradients 3–15%) divides formed on laterite with gravels dominant.	Loamy gravels, duplex sandy gravels, shallow gravels and deep sandy gravels
254PpCB	Carbunup Subsystem (Perup)	Minor valleys < 20 m deep with slopes < 5%. Soils are predominantly semi-wet soils with deep sandy gravels and pale deep sands with humus podzols in valley floors.	Deep sandy gravels, duplex sandy gravels, yellow deep sands and wet and semi-wet soils (sandy)
254PpCC	Catterick Subsystem	Shallow minor valleys (5–40 m relief) with gentle to low slopes (3–20%), soils are loamy gravels and loams, swampy valley floors.	Duplex sandy gravels, loamy gravels and wet and semi-wet soils
254PpCL	Corbalup Subsystem (Perup)	Gently undulating rises over sedimentary deposits, relief 5-15 m, slopes 1-5%. Soils are loamy gravels and sandy gravels.	Semi-wet soils, duplex sandy gravels, grey deep sandy duplexes and loamy gravels
254PpCO	Collis Subsystem (Perup)	Low hills and low hilly terrain; 20 m relief. Soils are predominantly gravelly.	Loamy gravels, duplex sandy gravels, shallow gravels and deep sandy gravels
254PpYR	Yornup Subsystem (Perup)	Swampy plains, drainage floors and semi-permanent swamps. Pale deep sands and sandy duplex soils are dominant.	Wet soils, semi-wet soils, pale deep sands and grey deep sandy duplexes

(DAFWA 2007)

Appendix E— The LUCICAT Live model

Streamflow, salt load and salinity for the Tweed/Gnowergerup subcatchments were calculated using the LUCICAT Live (Land Use Change Incorporated Catchment) model. The LUCICAT Live model is the new ‘user-friendly’ version of LUCICAT. The original, unlike LUCICAT Live, lacked a proper graphical user interface and its use was restricted to computer specialists.

The location of the response units in the catchment enables the spatial distribution of rainfall, pan evaporation, soil salt storage and land use to be taken into account in the modelling process and so allows calculations of daily flows, salt loads and salinities for each response unit. At scales larger than this (i.e. inside a response unit itself), a response unit is a purely conceptual salt and water balance without a spatial component and so the spatial distribution of plantings or other management activities within a response unit will have no influence on the response unit output at that scale. However, the proportion of a particular phenomenon or activity in a response unit is represented at the conceptual level. The spatial component for modelling at a catchment scale is achieved by individually setting geographically relevant parameters for each response unit.

The generated streamflows from each of the response units are routed downstream based on open channel hydraulics through a channel and stream network. Routing of streamflows are based on the DEM and this flow direction is shown in Figure 18. The channel link file represents the catchment stream network and determines how flow takes place in the model (and hence how the response units are linked). The nodes are points at the end of and at the intersections of the channel link file network and the reporting points for cumulative salt loads and streamflows (Figure 18). This enables the model to estimate streamflows, salt loads and salinities for the individual management units and the Tweed/Gnowergerup catchments (Bari 2005).

The model has a minimum number of physically meaningful parameters, most of which are estimated ‘a priori’ from catchment physical attributes and require minimal or no calibration. The term ‘a priori’ means that the parameters are estimated through theoretical or empirical relationships derived from measurable catchment characteristics; for example, the relationship between soil and vegetation characteristics; or between geomorphology and topography.

Catchment modelling with LUCICAT Live

Input data collation and pre-processing

Before using LUCICAT Live, an important but separate step is Geographic Information Systems (GIS) pre-processing. As with other catchment modelling tools, currently available data is in a raw format which cannot be used directly as input. The purpose of the GIS pre-processing stage is to prepare the input data required. All the input data is stored in a single input folder. The 'user friendly' features of LUCICAT Live can be used once the GIS pre-processing and input folder setup are accomplished.

The LUCICAT Live model performs calculations based on the following data:

- Digital Elevation Model (DEM)
- Landsat satellite data
- Aerial photography
- Rainfall
- Pan evaporation
- Gauging station data – flows and salinity
- Soils/geology

This is quite an intensive and timely process requiring the use of specialist GIS software (separate from LUCICAT Live). ArcMap was used for this project.

The GIS pre-processing develops the following derived data for the model:

- Channel link file — surface water hydrology and networking which contains channel attributes such as stream depth and width, Mannings coefficient and slope and connectivity
- Response units — subcatchment information including slope, area, soil depths, soil types, hydraulic conductivity and connectivity
- Nodes — stream junctions, beginnings and ends for surface water connectivity and flow order and direction
- Land-use files — also known as clearing history or vegetation history contain the essential land-use data required by LUCICAT for modelling scenarios. They contain type of vegetation (in the form of leaf area index and rooting depth) and the proportion of each response unit under a particular land use.

The historical Landsat scenes and aerial photography were used to produce the clearing history vegetation cover files, and the DEM was used to prepare the channel link files, response units and nodes.

The size and number of the response units was determined based on the availability of rainfall stations, stream network, topography, soil type and land-use history. To obtain an outlet which included flows from both the Tweed River and Gnowergerup Brook catchments, it was necessary to extend the modelled catchment boundaries to include Response Units 25 and 38. A total of 38 response units were generated for these catchments. The linkages and drainage directions between all the response units and nodes (in context of the management units) used by the model are shown in Figure 18.

Selection of the management units (Fig. 18) was based on grouping the response units in a way that allowed only one hydrological outlet per management unit. As there were several configurations available for grouping the various response units together, the BBG was consulted for the most suitable grouping. The BBG based the grouping on local knowledge of the land characteristics and the social aspects of catchment management (location of stakeholders).

Rainfall and pan evaporation data were obtained from gauging stations in or close to the catchment. The gauging station data was from the agency's own water monitoring database (WIN) for the Jayes Road gauging station. Although this gauging station only recorded data from Gnowergerup Brook, based on data availability and location in the catchment, it was the only suitable station that could be used for the area.

The current catchment land-use was determined from the 2007 clearing history vegetation cover file (or land-use data files generated). This land cover information (used in the LUCICAT modelling process) shows the statistics for the management units and catchments within the modelling catchment area.

Running LUCICAT Live — its principal components

Once the input folder was set up with all the required pre-processed data, LUCICAT Live was used for calibration, validation and running the 'base case' and scenarios.

The model consists of five main interfaces:

1. Project setup
2. Rainfall processor
3. Calibration
4. Calibration output
5. Scenario setup and analysis

In the 'rainfall processor' tab, rainfall data and pan evaporation are generated for all the individual response units using data from the gauging stations and response unit spatial data. The rainfall data was generated from the rainfall record, which, in this project, was 1 January 1979 to 31 December 2006.

In the 'calibration' tab, parameters such as saturated hydraulic conductivity were set via the user interface. The response units, channel link file, nodes and 2007 land use file (hence current vegetation cover) were loaded into the project and the model run. The model uses this data (in conjunction with the generated rainfall data and pan evaporation) to generate the daily streamflows, salt loads and salinities. The modelling period was set by the dates when the rainfall and stream gauging station data were available; that is, 1 January 1979 to 31 December 2006. Running the model generates files with modelled daily data for streamflows, salt loads and salinities for the selected nodes and response units.

In the 'calibration output' tab, the data from the modelled output files for salt load, flows and salinities for each response unit and selected node can be analysed via graphs generated by LUCICAT. Moreover, the observed and modelled data for the nodes can be compared, if the observed data is available. In this case, it was possible to compare the observed data at Jayes Road gauging station with the modelled data (node 74) on a daily, monthly and yearly basis. Correlation coefficients (R^2) calculated via the GUI estimate how well the modelled and observed data correlate (Figs 45–48).

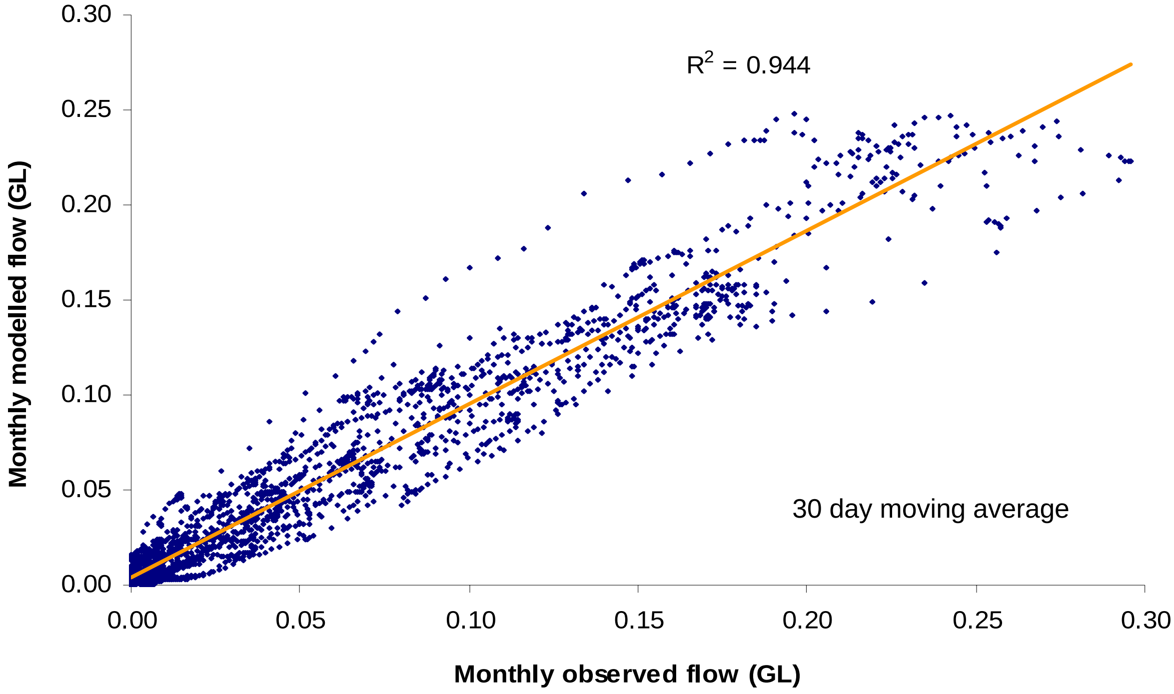

Figure 45 Correlation between observed and modelled monthly flows

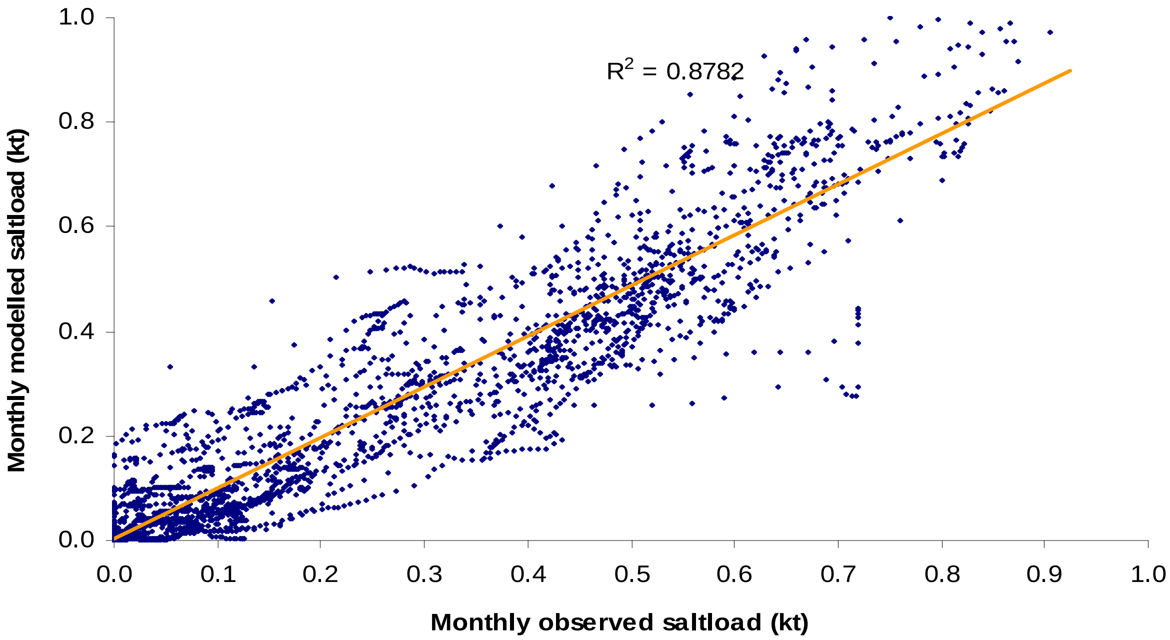

Figure 46 Correlation between observed and modelled salt loads

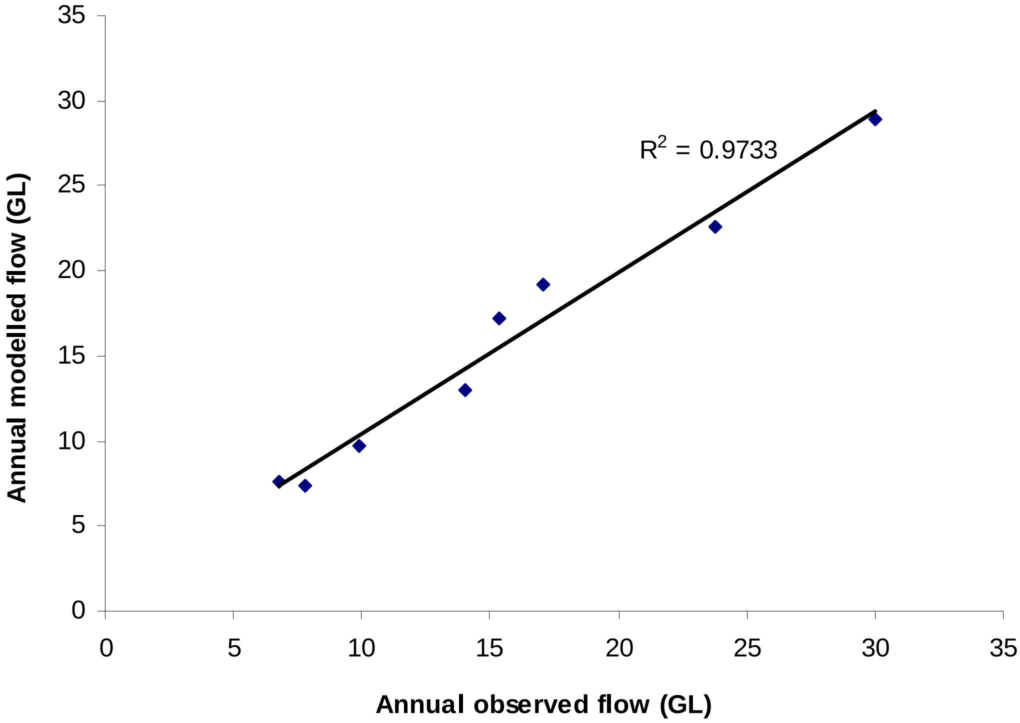

Figure 47 Correlation between observed and modelled annual flows

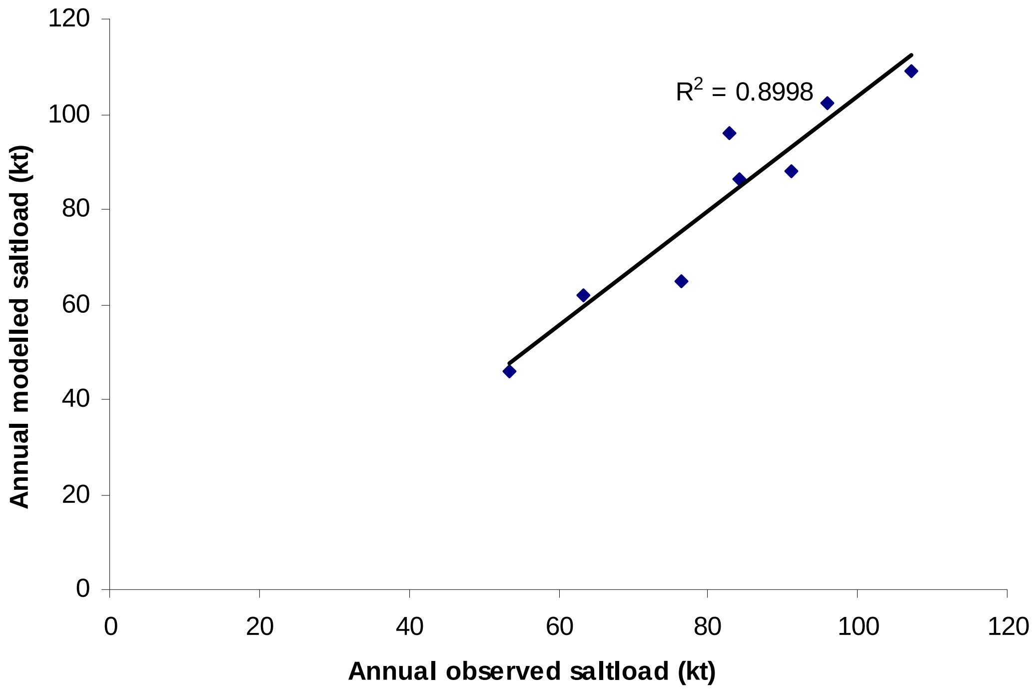

Figure 48 Correlation between observed and modelled annual salt loads

Once the level of correlation between the modelled and observed data is high enough via manipulation of the model parameters in the ‘calibration’ tab, the ‘base case’ and scenarios can be run.

In the ‘scenario setup and analysis’ tab, the first step is to extend the observed rainfall data ‘into the future’. By clicking the ‘extend time series data’ button, the observed rainfall data and pan evaporation are calculated for each response unit and ‘extended’ into the future to a specified date. The scenarios can then be created by clicking the ‘create new scenario’ button. The catchment land-use type and cover percentage; rooting depth, LAI and year of planting are set for the response units and the scenarios then run for the desired period, usually reflecting the number of repeated rainfall records.

Modelled data post-processing and presentation

The steps in this section are separate from running the LUCICAT Live model, and are used once all the modelling has been done.

Running the modelling scenarios produces a series of Excel files that contain the daily flows, salt loads and salinities for the selected nodes and all the response units, in addition to reporting files generated by the model to assess model performance and outputs. To summarise the data into the salinity situation at a given projected year (2030 and 2060 in this case), it is necessary to obtain a 10-year moving average to smooth out the data.

Performing these calculations and presenting them in a summary table and graphically manually is very time consuming, so an Excel workbook with a macro was used to extract and process this modelled data into a table and another macro in a separate workbook used to extract the modelled data and present it in a graph (Fig. 42).

Appendix F — Results of all management scenarios

Summary of management scenarios in 2030 — salinity

	Tweed River	Gnowergerup Brook (Jayes Rd gauging station)	Mayanup	Dwalganup Brook	South Kulikup	Kenninup	Scotts Brook	Rylington	Kingston	Entire area modelled (Tweed/Gnowergerup area outside)
Scenario	Salinity (mg/L) in 2030 (average of 2025–35)									
Base case (1)	3150	4636	4638	3987	4853	6197	3561	2675	1922	4071
All cleared (5)	3705	4998	5232	5369	5185	6037	4117	2467	2402	4394
22% upland trees (6)	2926	4278	4644	4002	4370	473	3646	1834	1395	3761
25% lowland trees (7)	2438	3975	3427	2439	3783	6185	3565	2673	1921	3362
55% upland trees (8)	2193	3804	4462	3651	3125	473	3066	338	386	3307
55% lowland trees (9)	626	3395	3046	377	3779	473	3565	577	1226	2695
55% upland perennials (10)	2186	4133	4498	3396	3895	5127	3187	790	894	3537
55% lowland perennials (11)	1205	3885	3701	1340	4182	5127	3561	929	1447	3174
59% strategic trees (3)	1861	2154	1947	377	2897	473	1737	2673	1921	2089
59% strategic trees & remainder perennials (3.5 m) (4)	641	1039	906	381	1544	473	808	787	893	997
59% strategic trees & remainder perennials (5 m) (12)	580	968	859	381	1434	473	736	693	778	926
82% upland trees (2)	2260	2635	3822	4021	1262	473	464	337	388	2585
88% lowland trees (13)	437	1305	829	388	515	473	2490	577	477	1369
100% trees (14)	356	588	552	358	809	473	464	337	388	563
100% native veg. (15)	317	308	280	374	335	391	308	281	313	304

Summary of management scenarios at 2060 – salinity

	Tweed River	Gnowergerup Brook (Jayes Rd gauging station)	Mayanup	Dwalganup Brook	South Kulikup	Kenninup	Scotts Brook	Rylington	Kingston	Entire area modelled (Tweed/Gnowergerup area outside)
Scenario	Salinity (mg/L) in 2060 (average of 2055–65)									
Base case (1)	3011	4613	4549	3672	4803	6275	3632	2624	1977	4026
All cleared (5)	5334	6135	5796	5759	6323	7002	6173	5311	4595	5631
22% upland trees (6)	2784	4228	4560	3686	4215	425	3708	1821	1433	3700
25% lowland trees (7)	2353	4009	3463	2236	3722	6269	3634	2624	1976	3368
55% upland trees (8)	2027	3706	4307	3272	2883	425	3151	347	344	3219
55% lowland trees (9)	627	3384	2989	427	3712	425	3636	594	1226	2699
55% upland perennials (10)	1972	3964	4321	3040	3607	4698	3218	679	611	3384
55% lowland perennials (11)	1007	3742	3439	913	4075	4698	3632	835	1405	3042
59% strategic trees (3)	1781	2128	1847	427	2826	425	1848	2623	1976	2069
59% strategic trees & remainder perennials (3.5 m) (4)	543	738	603	432	1055	425	674	675	610	705
59% strategic trees & remainder perennials (5 m) (12)	456	585	484	432	812	425	548	518	486	546
82% upland trees (2)	2140	2469	3602	3676	903	425	397	345	343	2490
88% lowland trees (13)	442	1100	311	417	376	425	2515	594	343	1308
100% trees (14)	360	340	285	392	352	425	397	345	343	338
100% native veg. (15)	345	331	295	400	362	433	336	302	345	327

Scenario 1

Base case - 2007 land use	Tweed River	Gnowergerup Brook	Mayanup	Dwalganup Brook	South Kulikup	Kenninup	Scotts Brook	Rylington	Kingston	Entire area modelled (Tweed/ Gnowergerup+ area outside)
Area (km^2)	236	377	148	108	91	37	101	75	53	661
Lake area (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 native forest (km^2)	139	112	36	51	22	5	49	48	39	263
Total 2007 native forest (%)	59	30	24	48	24	14	48	64	74	40
Total 2007 trees (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 trees (%)	0	0	0	0	0	0	0	0	0	0
Total 2007 cleared area (km^2)	97	265	112	57	69	32	52	27	14	398
Total 2007 cleared area (%)	41	70	76	52	76	86	52	36	26	60
Total 2007 perennial pasture (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 perennial pasture (%)	0	0	0	0	0	0	0	0	0	0
Average for 2030 a										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	5.17	14.38	7.00	2.37	3.43	1.51	2.93	1.92	0.88	21.86
Runoff (mm)	21.92	39.07	47.31	22.03	37.60	41.26	29.00	25.54	16.57	33.07
Salt load (kt)	16.28	66.68	32.47	9.47	16.64	9.38	10.42	5.13	1.68	88.98
Salinity (mg/L)	3150	4636	4638	3987	4853	6197	3561	2675	1922	4071
Groundwater discharge to stream zone	4.99	14.58	14.44	6.27	16.60	12.40	6.83	5.08	2.25	9.15
Baseflow (mm)	4.27	2.09	2.07	7.85	0.29	3.73	0.17	2.15	0.00	2.32
Average for 2060 b										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	5.03	13.95	6.90	2.37	3.30	1.46	2.79	1.83	0.83	21.27
Runoff (mm)	21.33	37.89	46.61	22.00	36.16	39.75	27.63	24.32	15.72	32.18
Salt load (kt)	15.14	64.35	31.38	8.71	15.84	9.16	10.13	4.79	1.64	85.63
Average annual salinity (mg/L)	3011	4613	4549	3672	4803	6275	3632	2624	1977	4026
Groundwater discharge to stream zone	4.71	14.29	14.16	5.80	16.45	12.15	6.88	4.89	2.23	8.94
Baseflow (mm)	4.28	2.09	2.07	7.88	0.29	3.69	0.18	2.13	0.00	2.32

a annual mean for the period 2025 – 2035

b annual mean for the period 2055 – 2065

Scenario 5

All cleared	Tweed River	Gnowergerup Brook	Mayanup	Dwalganup Brook	South Kulikup	Kenninup	Scotts Brook	Rylington	Kingston	Entire area modelled (Tweed/ Gnowergerup+ area outside)
Area (km^2)	236	377	148	108	91	37	101	75	53	661
Lake area (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 native forest (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 native forest (%)	0	0	0	0	0	0	0	0	0	0
Total 2007 trees (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 trees (%)	0	0	0	0	0	0	0	0	0	0
Total 2007 cleared area (km^2)	236	377	148	108	91	37	101	75	53	661
Total 2007 cleared area (%)	100	100	100	100	100	100	100	100	100	100
Total 2007 perennial pasture (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 perennial pasture (%)	0	0	0	0	0	0	0	0	0	0
Average for 2030 a										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	11.44	20.60	9.29	4.93	4.78	1.70	5.44	4.16	2.35	35.06
Runoff (mm)	48.51	55.96	62.77	45.76	52.39	46.32	53.92	55.36	44.37	53.03
Salt load (kt)	42.38	102.98	48.59	26.49	24.77	10.26	22.40	10.26	5.63	154.03
Salinity (mg/L)	3705	4998	5232	5369	5185	6037	4117	2467	2402	4394
Groundwater discharge to stream zone	12.09	21.62	21.44	16.72	18.08	18.03	14.64	9.12	6.87	15.49
Baseflow (mm)	4.48	2.69	2.67	7.92	0.29	2.74	2.56	2.19	0.72	2.41
Average for 2060 b										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	14.32	22.65	9.92	5.57	5.23	1.77	6.38	5.73	3.02	40.24
Runoff (mm)	60.74	61.52	67.03	51.68	57.30	48.12	63.26	76.23	57.20	60.88
Salt load (kt)	76.40	138.94	57.48	32.09	33.04	12.37	39.40	30.41	13.90	226.60
Average annual salinity (mg/L)	5334	6135	5796	5759	6323	7002	6173	5311	4595	5631
Groundwater discharge to stream zone	20.64	25.44	25.37	20.39	21.44	23.48	24.25	24.56	15.55	22.01
Baseflow (mm)	5.18	3.43	3.43	6.30	0.39	3.96	3.98	5.06	3.07	2.78

a annual mean for the period 2025 – 2035

b annual mean for the period 2055 – 2065

Scenario 6

22% upland trees

	Tweed River	Gnowergerup Brook	Mayanup	Dwalganup Brook	South Kulikup	Kenninup	Scotts Brook	Rylington	Kingston	Entire area modelled (Tweed/ Gnowergerup+ area outside)
Area (km^2)	236	377	148	108	91	37	101	75	53	661
Lake area (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 native forest (km^2)	139	112	36	51	22	5	49	48	39	263
Total 2007 native forest (%)	59	30	24	48	24	14	48	64	74	40
Total 2007 trees (km^2)	18	62	0	0	25	32	5	13	4	79
Total 2007 trees (%)	7	16	0	0	28	86	5	18	8	12
Total 2007 cleared area (km^2)	79	203	112	57	44	0	47	13	9	319
Total 2007 cleared area (%)	34	54	76	52	48	0	47	18	18	48
Total 2007 perennial pasture (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 perennial pasture (%)	0	0	0	0	0	0	0	0	0	0
Average for 2030 a										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	4.46	12.10	6.99	2.38	2.51	0.22	2.86	1.40	0.67	18.86
Runoff (mm)	18.90	32.85	47.26	22.08	27.53	5.89	28.35	18.65	12.76	28.54
Salt load (kt)	13.04	51.75	32.48	9.53	10.97	0.10	10.43	2.57	0.94	70.94
Salinity (mg/L)	2926	4278	4644	4002	4370	473	3646	1834	1395	3761
Groundwater discharge to stream zone	4.01	14.70	14.40	6.23	0.15	8.43	6.85	2.75	1.25	7.35
Baseflow (mm)	4.27	1.89	1.87	7.85	0.29	2.93	0.10	2.15	0.00	1.81
Average for 2060 b										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	4.35	11.72	6.89	2.38	2.39	0.20	2.73	1.33	0.64	18.37
Runoff (mm)	18.43	31.85	46.59	22.05	26.25	5.34	27.07	17.71	12.07	27.78
Salt load (kt)	12.10	49.57	31.43	8.76	10.09	0.08	10.13	2.42	0.91	67.97
Average annual salinity (mg/L)	2784	4228	4560	3686	4215	425	3708	1821	1433	3700
Groundwater discharge to stream zone	3.79	14.40	14.11	5.79	0.00	7.97	6.90	2.73	1.22	7.12
Baseflow (mm)	4.28	1.92	1.90	7.88	0.29	2.82	0.10	2.13	0.00	1.60

a annual mean for the period 2025 – 2035
b annual mean for the period 2055 – 2065

Scenario 7

25% lowland trees

	Tweed River	Gnowergerup Brook	Mayanup	Dwalganup Brook	South Kulikup	Kenninup	Scotts Brook	Rylington	Kingston	Entire area modelled (Tweed/ Gnowergerup+ area outside)
Area (km^2)	236	377	148	108	91	37	101	75	53	661
Lake area (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 native forest (km^2)	139	112	36	51	22	5	49	48	39	263
Total 2007 native forest (%)	59	30	24	48	24	14	48	64	74	40
Total 2007 trees (km^2)	15	76	54	15	22	0	0	0	0	91
Total 2007 trees (%)	6	20	36	14	24	0	0	0	0	14
Total 2007 cleared area (km^2)	82	189	59	42	47	32	52	27	14	307
Total 2007 cleared area (%)	35	50	40	39	52	86	52	36	26	47
Total 2007 perennial pasture (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 perennial pasture (%)	0	0	0	0	0	0	0	0	0	0
Average for 2030 a										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	4.32	10.63	3.94	1.53	2.32	1.51	2.93	1.92	0.88	16.87
Runoff (mm)	18.34	28.88	26.61	14.19	25.48	41.13	29.04	25.54	16.57	25.52
Salt load (kt)	10.54	42.27	13.50	3.73	8.79	9.34	10.44	5.13	1.68	56.71
Salinity (mg/L)	2438	3975	3427	2439	3783	6185	3565	2673	1921	3362
Groundwater discharge to stream zone	3.32	6.16	6.24	2.61	16.52	6.83	6.85	5.08	2.25	5.96
Baseflow (mm)	1.42	0.94	0.95	1.61	0.29	3.18	0.17	2.15	0.00	1.05
Average for 2060 b										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	4.18	10.21	3.83	1.53	2.21	1.46	2.79	1.83	0.83	16.29
Runoff (mm)	17.74	27.74	25.87	14.15	24.20	39.66	27.65	24.31	15.72	24.64
Salt load (kt)	9.84	40.94	13.26	3.41	8.22	9.13	10.14	4.79	1.64	54.85
Average annual salinity (mg/L)	2353	4009	3463	2236	3722	6269	3634	2624	1976	3368
Groundwater discharge to stream zone	3.09	6.07	6.15	2.27	16.41	6.25	6.90	4.87	2.23	5.77
Baseflow (mm)	0.00	0.86	0.88	-1.48	0.29	2.88	0.18	2.13	0.00	0.37

a annual mean for the period 2025 – 2035

b annual mean for the period 2055 – 2065

55% upland trees	**Tweed River**	**Gnowergerup Brook**	**Mayanup**	**Dwalganup Brook**	**South Kulikup**	**Kenninup**	**Scotts Brook**	**Rylington**	**Kingston**	**Entire area modelled (Tweed/ Gnowergerup+ area outside)**
Area (km^2)	236	377	148	108	91	37	101	75	53	661
Lake area (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 native forest (km^2)	139	112	36	51	22	5	49	48	39	263
Total 2007 native forest (%)	59	30	24	48	24	14	48	64	74	40
Total 2007 trees (km^2)	66	134	31	25	41	32	30	27	14	200
Total 2007 trees (%)	28	36	21	23	46	86	30	36	26	30
Total 2007 cleared area (km^2)	31	131	82	31	28	0	21	0	0	198
Total 2007 cleared area (%)	13	35	55	29	30	0	21	0	0	30
Total 2007 perennial pasture (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 perennial pasture (%)	0	0	0	0	0	0	0	0	0	0
Average for 2030 a										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	2.91	9.22	5.75	1.62	1.73	0.22	2.01	0.84	0.45	14.46
Runoff (mm)	12.36	25.04	38.83	15.07	18.97	5.89	19.94	11.14	8.56	21.87
Salt load (kt)	6.39	35.06	25.64	5.93	5.41	0.10	6.17	0.28	0.17	47.81
Salinity (mg/L)	2193	3804	4462	3651	3125	473	3066	338	386	3307
Groundwater discharge to stream zone	1.85	11.76	11.47	3.92	0.15	4.51	4.05	0.11	0.13	4.96
Baseflow (mm)	1.42	1.71	1.68	1.61	0.29	2.13	0.05	2.15	0.00	0.86
Average for 2060 b										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	2.85	8.91	5.66	1.64	1.62	0.20	1.92	0.79	0.43	14.07
Runoff (mm)	12.10	24.20	38.23	15.20	17.81	5.34	19.07	10.49	8.06	21.29
Salt load (kt)	5.78	33.02	24.37	5.36	4.68	0.08	6.06	0.27	0.15	45.30
Average annual salinity (mg/L)	2027	3706	4307	3272	2883	425	3151	347	344	3219
Groundwater discharge to stream zone	1.69	11.31	11.02	3.63	0.00	3.60	4.02	0.10	0.00	4.64
Baseflow (mm)	0.00	1.43	1.40	-1.48	0.29	1.67	0.00	2.13	0.00	0.00

a annual mean for the period 2025 – 2035

b annual mean for the period 2055 – 2065

Scenario 8

Scenario 9

55% lowland trees	Tweed River	Gnowergerup Brook	Mayanup	Dwalganup Brook	South Kulikup	Kenninup	Scotts Brook	Rylington	Kingston	Entire area modelled (Tweed/ Gnowergerup+ area outside)
Area (km^2)	236	377	148	108	91	37	101	75	53	661
Lake area (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 native forest (km^2)	139	112	36	51	22	5	49	48	39	263
Total 2007 native forest (%)	59	30	24	48	24	14	48	64	74	40
Total 2007 trees (km^2)	69	130	72	43	27	32	0	22	4	199
Total 2007 trees (%)	29	35	48	40	29	86	0	29	7	30
Total 2007 cleared area (km^2)	28	135	41	13	42	0	52	5	10	199
Total 2007 cleared area (%)	12	36	27	12	46	0	52	7	19	30
Total 2007 perennial pasture (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 perennial pasture (%)	0	0	0	0	0	0	0	0	0	0
Average for 2030 a										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	2.35	8.46	3.20	0.69	2.18	0.22	2.93	0.96	0.70	12.74
Runoff (mm)	9.97	22.99	21.66	6.43	23.93	5.89	29.04	12.81	13.17	19.27
Salt load (kt)	1.47	28.74	9.76	0.06	8.25	0.10	10.45	0.55	0.85	34.33
Salinity (mg/L)	626	3395	3046	377	3779	473	3565	577	1226	2695
Groundwater discharge to stream zone	0.40	4.63	4.67	0.03	0.15	6.54	6.85	0.41	1.14	3.61
Baseflow (mm)	1.42	0.79	0.80	1.61	0.52	2.63	0.10	2.15	0.00	1.05
Average for 2060 b										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	2.27	8.09	3.11	0.70	2.06	0.20	2.79	0.91	0.65	12.26
Runoff (mm)	9.61	21.97	21.00	6.53	22.63	5.34	27.68	12.08	12.38	18.55
Salt load (kt)	1.42	27.37	9.29	0.08	7.66	0.08	10.15	0.54	0.80	33.09
Average annual salinity (mg/L)	627	3384	2989	427	3712	425	3636	594	1226	2699
Groundwater discharge to stream zone	0.37	4.37	4.41	0.05	0.00	5.95	6.93	0.40	0.99	3.46
Baseflow (mm)	0.00	0.84	0.84	-1.48	0.00	2.25	0.09	2.13	0.00	0.37

a annual mean for the period 2025 – 2035

b annual mean for the period 2055 – 2065

55% upland perennials	Tweed River	Gnowergerup Brook	Mayanup	Dwalganup Brook	South Kulikup	Kenninup	Scotts Brook	Rylington	Kingston	Entire area modelled (Tweed/ Gnowergerup+ area outside)
Area (km^2)	236	377	148	108	91	37	101	75	53	661
Lake area (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 native forest (km^2)	139	112	36	51	22	5	49	48	39	263
Total 2007 native forest (%)	59	30	24	48	24	14	48	64	74	40
Total 2007 trees (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 trees (%)	0	0	0	0	0	0	0	0	0	0
Total 2007 cleared area (km^2)	31	131	82	31	28	0	21	0	0	198
Total 2007 cleared area (%)	13	35	55	29	30	0	21	0	0	30
Total 2007 perennial pasture (km^2)	66	134	31	25	41	32	30	27	14	200
Total 2007 perennial pasture (%)	28	36	21	23	46	86	30	36	26	30
Average for 2030 a										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	3.31	10.78	6.11	1.75	2.24	0.67	2.24	1.04	0.52	16.41
Runoff (mm)	14.04	29.27	41.29	16.26	24.56	18.35	22.22	13.79	9.89	24.82
Salt load (kt)	7.24	44.55	27.48	5.95	8.72	3.45	7.14	0.82	0.47	58.05
Salinity (mg/L)	2186	4133	4498	3396	3895	5127	3187	790	894	3537
Groundwater discharge to stream zone	2.33	12.56	12.33	4.07	6.95	7.27	4.87	0.97	0.70	6.19
Baseflow (mm)	4.28	2.07	2.06	7.87	0.29	3.79	0.14	2.15	0.00	2.48
Average for 2060 b										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	3.18	10.15	5.94	1.76	2.04	0.55	2.11	0.95	0.47	15.63
Runoff (mm)	13.49	27.56	40.17	16.30	22.34	15.06	20.88	12.66	8.97	23.65
Salt load (kt)	6.28	40.22	25.68	5.34	7.35	2.60	6.78	0.65	0.29	52.91
Average annual salinity (mg/L)	1972	3964	4321	3040	3607	4698	3218	679	611	3384
Groundwater discharge to stream zone	1.98	12.02	11.79	3.60	5.53	6.34	4.74	0.77	0.40	5.69
Baseflow (mm)	3.99	2.11	2.09	7.25	0.29	3.66	0.10	2.13	0.00	2.39

a annual mean for the period 2025 – 2035

b annual mean for the period 2055 – 2065

Scenario 10

Scenario 11

55% lowland perennials	Tweed River	Gnowergerup Brook	Mayanup	Dwalganup Brook	South Kulikup	Kenninup	Scotts Brook	Rylington	Kingston	Entire area modelled (Tweed/ Gnowergerup+ area outside)
Area (km^2)	236	377	148	108	91	37	101	75	53	661
Lake area (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 native forest (km^2)	139	112	36	51	22	5	49	48	39	263
Total 2007 native forest (%)	59	30	24	48	24	14	48	64	74	40
Total 2007 trees (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 trees (%)	0	0	0	0	0	0	0	0	0	0
Total 2007 cleared area (km^2)	28	135	41	13	42	0	52	5	10	199
Total 2007 cleared area (%)	12	36	27	12	46	0	52	7	19	30
Total 2007 perennial pasture (km^2)	69	130	72	43	27	32	0	22	4	199
Total 2007 perennial pasture (%)	29	35	48	40	29	86	0	29	7	30
Average for 2030 a										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	2.84	10.29	4.34	0.99	2.55	0.67	2.93	1.12	0.73	15.18
Runoff (mm)	12.03	27.96	29.36	9.17	27.98	18.35	29.00	14.93	13.74	22.96
Salt load (kt)	3.42	39.98	16.08	1.32	10.67	3.45	10.42	1.04	1.05	48.17
Salinity (mg/L)	1205	3885	3701	1340	4182	5127	3561	929	1447	3174
Groundwater discharge to stream zone	1.32	7.71	7.70	1.31	6.95	8.51	6.83	1.24	1.45	5.25
Baseflow (mm)	4.28	1.99	1.98	7.87	0.47	3.82	0.13	2.15	0.00	2.32
Average for 2060 b										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	2.66	9.60	4.06	0.95	2.38	0.55	2.79	1.03	0.67	14.27
Runoff (mm)	11.28	26.07	27.45	8.83	26.07	15.06	27.63	13.78	12.75	21.58
Salt load (kt)	2.68	35.91	13.97	0.87	9.69	2.60	10.13	0.86	0.95	43.40
Average annual salinity (mg/L)	1007	3742	3439	913	4075	4698	3632	835	1405	3042
Groundwater discharge to stream zone	1.01	6.74	6.75	0.84	5.53	7.86	6.88	1.03	1.33	4.78
Baseflow (mm)	3.99	1.77	1.76	7.25	0.51	3.78	0.10	2.13	0.00	2.24

a annual mean for the period 2025 – 2035
b annual mean for the period 2055 – 2065

Scenario 3

59% strategic trees

	Tweed River	Gnowergerup Brook	Mayanup	Dwalganup Brook	South Kulikup	Kenninup	Scotts Brook	Rylington	Kingston	Entire area modelled (Tweed/ Gnowergerup+ area outside)
Area (km^2)	236	377	148	108	91	37	101	75	53	661
Lake area (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 native forest (km^2)	139	112	36	51	22	5	49	48	39	263
Total 2007 native forest (%)	59	30	24	48	24	14	48	64	74	40
Total 2007 trees (km^2)	32	180	92	32	36	32	21	0	0	212
Total 2007 trees (%)	14	48	62	30	39	86	21	0	0	32
Total 2007 cleared area (km^2)	64	85	21	24	33	0	31	27	14	186
Total 2007 cleared area (%)	27	23	14	22	37	0	31	36	26	28
Total 2007 perennial pasture (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 perennial pasture (%)	0	0	0	0	0	0	0	0	0	0
Average for 2030 a										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	3.63	5.82	2.28	0.84	1.69	0.22	1.71	1.92	0.88	11.40
Runoff (mm)	15.39	15.81	15.40	7.75	18.56	5.89	16.92	25.54	16.57	17.24
Salt load (kt)	6.75	12.54	4.44	-0.05	4.91	0.10	2.97	5.13	1.68	23.80
Salinity (mg/L)	1861	2154	1947	377	2897	473	1737	2673	1921	2089
Groundwater discharge to stream zone	2.26	2.18	2.19	0.31	0.15	3.88	2.05	5.07	2.25	2.64
Baseflow (mm)	1.42	0.33	0.34	1.61	0.52	1.19	0.17	2.15	0.00	1.05
Average for 2060 b										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	3.50	5.50	2.20	0.84	1.59	0.20	1.60	1.83	0.83	10.92
Runoff (mm)	14.82	14.94	14.84	7.78	17.40	5.34	15.82	24.31	15.71	16.52
Salt load (kt)	6.22	11.71	4.06	-0.21	4.48	0.08	2.95	4.79	1.64	22.60
Average annual salinity (mg/L)	1781	2128	1847	427	2826	425	1848	2623	1976	2069
Groundwater discharge to stream zone	2.09	1.99	1.99	0.09	0.00	3.32	1.98	4.86	2.23	2.42
Baseflow (mm)	0.00	0.25	0.26	-1.48	0.00	0.66	0.18	2.13	0.00	0.37

a annual mean for the period 2025 – 2035
b annual mean for the period 2055 – 2065

Strategic trees and perennials to 3.5m rooting depth

	Tweed River	Gnowergerup Brook	Mayanup	Dwalganup Brook	South Kulikup	Kenninup	Scotts Brook	Rylington	Kingston	Entire area modelled (Tweed/ Gnowergerup+ area outside)
Area (km^2)	236	377	148	108	91	37	101	75	53	661
Lake area (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 native forest (km^2)	139	112	36	51	22	5	49	48	39	263
Total 2007 native forest (%)	59	30	24	48	24	14	48	64	74	40
Total 2007 trees (km^2)	32	180	92	32	36	32	21	0	0	212
Total 2007 trees (%)	14	48	62	30	39	86	21	0	0	32
Total 2007 cleared area (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 cleared area (%)	0	0	0	0	0	0	0	0	0	0
Total 2007 perennial pasture (km^2)	64	85	21	24	33	0	31	27	14	186
Total 2007 perennial pasture (%)	27	23	14	22	37	0	31	36	26	28
Average for 2030 a										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	2.19	3.92	1.74	0.63	0.95	0.22	1.10	1.04	0.52	6.92
Runoff (mm)	9.28	10.64	11.74	5.84	10.45	5.89	10.86	13.78	9.88	10.46
Salt load (kt)	1.40	4.07	1.57	0.12	1.47	0.10	0.89	0.81	0.47	6.90
Salinity (mg/L)	641	1039	906	381	1544	473	808	787	893	997
Groundwater discharge to stream zone	0.46	0.83	0.84	0.00	0.15	1.49	0.76	0.96	0.70	0.87
Baseflow (mm)	1.42	0.38	0.38	1.66	0.52	0.86	0.14	2.07	0.00	1.20
Average for 2060 b										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	2.08	3.56	1.63	0.65	0.84	0.20	0.98	0.95	0.47	6.32
Runoff (mm)	8.81	9.68	11.04	6.06	9.19	5.34	9.74	12.64	8.96	9.56
Salt load (kt)	1.13	2.63	0.98	0.20	0.88	0.08	0.66	0.64	0.29	4.45
Average annual salinity (mg/L)	543	738	603	432	1055	425	674	675	610	705
Groundwater discharge to stream zone	0.33	0.46	0.46	-0.01	0.00	0.77	0.54	0.76	0.39	0.50
Baseflow (mm)	0.00	0.15	0.15	-1.37	0.00	0.50	0.10	1.97	0.00	0.50

a annual mean for the period 2025 – 2035

b annual mean for the period 2055 – 2065

Scenario 4

Scenario 12

Strategic trees and perennials to 5m rooting depth	Tweed River	Gnowergerup Brook	Mayanup	Dwalganup Brook	South Kulikup	Kenninup	Scotts Brook	Rylington	Kingston	Entire area modelled (Tweed/ Gnowergerup+ area outside)
Area (km^2)	236	377	148	108	91	37	101	75	53	661
Lake area (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 native forest (km^2)	139	112	36	51	22	5	49	48	39	263
Total 2007 native forest (%)	59	30	24	48	24	14	48	64	74	40
Total 2007 trees (km^2)	32	180	92	32	36	32	21	0	0	212
Total 2007 trees (%)	14	48	62	30	39	86	21	0	0	32
Total 2007 cleared area (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 cleared area (%)	0	0	0	0	0	0	0	0	0	0
Total 2007 perennial pasture (km^2)	64	85	21	24	33	0	31	27	14	186
Total 2007 perennial pasture (%)	27	23	14	22	37	0	31	36	26	28
Average for 2030 a										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	2.13	3.83	1.71	0.63	0.92	0.22	1.07	1.00	0.51	6.73
Runoff (mm)	9.05	10.41	11.56	5.83	10.06	5.89	10.62	13.30	9.58	10.18
Salt load (kt)	1.24	3.71	1.47	0.15	1.32	0.10	0.79	0.69	0.39	6.23
Salinity (mg/L)	580	968	859	381	1434	473	736	693	778	926
Groundwater discharge to stream zone	0.39	0.80	0.81	0.00	0.15	1.34	0.71	0.81	0.60	0.79
Baseflow (mm)	1.42	0.35	0.36	1.71	0.52	0.89	0.11	1.99	0.00	1.20
Average for 2060 b										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	2.03	3.47	1.60	0.65	0.80	0.20	0.96	0.92	0.46	6.12
Runoff (mm)	8.60	9.41	10.81	6.05	8.76	5.34	9.52	12.19	8.71	9.26
Salt load (kt)	0.92	2.03	0.77	0.23	0.65	0.08	0.53	0.47	0.22	3.35
Average annual salinity (mg/L)	456	585	484	432	812	425	548	518	486	546
Groundwater discharge to stream zone	0.20	0.34	0.35	0.00	0.00	0.53	0.44	0.48	0.21	0.34
Baseflow (mm)	0.00	0.22	0.21	-1.13	0.00	0.37	0.10	1.62	0.00	0.42

a annual mean for the period 2025 – 2035
b annual mean for the period 2055 – 2065

82% upland trees	Tweed River	Gnowergerup Brook	Mayanup	Dwalganup Brook	South Kulikup	Kenninup	Scotts Brook	Rylington	Kingston	Entire area modelled (Tweed/ Gnowergerup+ area outside)
Area (km^2)	236	377	148	108	91	37	101	75	53	661
Lake area (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 native forest (km^2)	139	112	36	51	22	5	49	48	39	263
Total 2007 native forest (%)	59	30	24	48	24	14	48	64	74	40
Total 2007 trees (km^2)	81	217	69	41	64	32	52	27	14	298
Total 2007 trees (%)	35	58	47	38	71	86	52	36	26	45
Total 2007 cleared area (km^2)	15	48	43	15	5	0	0	0	0	100
Total 2007 cleared area (%)	7	13	29	14	5	0	0	0	0	15
Total 2007 perennial pasture (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 perennial pasture (%)	0	0	0	0	0	0	0	0	0	0
Average for 2030 a										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	2.71	5.41	3.91	1.41	0.84	0.22	0.93	0.85	0.45	10.47
Runoff (mm)	11.51	14.69	26.43	13.08	9.23	5.89	9.23	11.30	8.59	15.84
Salt load (kt)	6.13	14.25	14.95	5.67	1.06	0.10	0.43	0.29	0.18	27.08
Salinity (mg/L)	2260	2635	3822	4021	1262	473	464	337	388	2585
Groundwater discharge to stream zone	1.73	7.00	6.76	3.64	0.15	0.97	0.35	0.11	0.13	2.78
Baseflow (mm)	1.42	0.97	0.95	3.03	0.52	0.68	0.05	0.11	0.00	0.86
Average for 2060 b										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	2.66	5.17	3.85	1.43	0.77	0.20	0.85	0.80	0.43	10.17
Runoff (mm)	11.28	14.05	26.02	13.29	8.48	5.34	8.40	10.64	8.08	15.38
Salt load (kt)	5.69	12.77	13.87	5.27	0.70	0.08	0.34	0.28	0.15	25.31
Average annual salinity (mg/L)	2140	2469	3602	3676	903	425	397	345	343	2490
Groundwater discharge to stream zone	1.65	6.40	6.17	3.53	0.00	0.30	0.18	0.10	0.00	2.50
Baseflow (mm)	0.00	0.70	0.68	0.00	0.00	0.21	0.00	0.00	0.00	0.00

a annual mean for the period 2025 – 2035

b annual mean for the period 2055 – 2065

Scenario 2

Scenario 13

88% lowland trees	Tweed River	Gnowergerup Brook	Mayanup	Dwalganup Brook	South Kulikup	Kenninup	Scotts Brook	Rylington	Kingston	Entire Area Modelled (Tweed/Gnowergerup + Area Outside)
Area (km^2)	236	377	148	108	91	37	101	75	53	661
Lake area (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 native forest (km^2)	139	112	36	51	22	5	49	48	39	263
Total 2007 native forest (%)	59	30	24	48	24	14	48	64	74	40
Total 2007 trees (km^2)	86	235	112	56	69	32	21	22	8	320
Total 2007 trees (%)	36	62	76	52	76	86	21	29	15	48
Total 2007 cleared area (km^2)	11	30	0	1	0	0	30	5	6	78
Total 2007 cleared area (%)	5	8	0	1	0	0	30	7	11	12
Total 2007 perennial pasture (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 perennial pasture (%)	0	0	0	0	0	0	0	0	0	0
Average for 2030 a										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	2.05	4.14	1.49	0.58	0.69	0.22	1.83	0.96	0.51	8.17
Runoff (mm)	8.70	11.25	10.05	5.41	7.52	5.89	18.18	12.81	9.58	12.36
Salt load (kt)	0.90	5.41	0.31	0.16	0.35	0.10	4.57	0.55	0.19	11.18
Salinity (mg/L)	437	1305	829	388	515	473	2490	577	477	1369
Groundwater discharge to stream zone (mm)	0.19	0.38	0.42	0.07	0.15	0.69	3.12	0.41	0.13	1.21
Baseflow (mm)	1.42	0.31	0.32	3.03	0.52	1.06	0.05	0.11	0.00	0.86
Average for 2060 b										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	1.99	3.84	1.41	0.61	0.62	0.20	1.70	0.91	0.47	7.79
Runoff (mm)	8.43	10.44	9.55	5.62	6.76	5.34	16.85	12.08	8.97	11.78
Salt load (kt)	0.88	4.23	-0.17	0.19	-0.02	0.08	4.27	0.54	0.15	10.19
Average annual salinity (mg/L)	442	1100	311	417	376	425	2515	594	343	1308
Groundwater discharge to stream zone (mm)	0.10	-0.06	-0.01	-0.06	0.00	0.00	3.06	0.40	0.00	0.98
Baseflow (mm)	0.00	0.11	0.12	0.00	0.00	0.63	0.00	0.00	0.00	0.00

a annual mean for the period 2025 – 2035
b annual mean for the period 2055 – 2065

Scenario 14

100% plantation trees	Tweed River	Jayes Rd GS	Mayanup	Dwalganup Brook	South Kulikup	Kenninup	Scotts Brook	Rylington	Kingston	Entire Area Modelled (Tweed/Gnowergerup + Area Outside)
Area (km^2)	236	377	148	108	91	37	101	75	53	661
Lake area (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 native forest (km^2)	139	112	36	51	22	5	49	48	39	263
Total 2007 native forest (%)	59	30	24	48	24	14	48	64	74	40
Total 2007 trees (km^2)	97	265	112	57	69	32	52	27	14	398
Total 2007 trees (%)	41	70	76	52	76	86	52	36	26	60
Total 2007 cleared area (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 cleared area (%)	0	0	0	0	0	0	0	0	0	0
Total 2007 perennial pasture (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 perennial pasture (%)	0	0	0	0	0	0	0	0	0	0
Average for 2030 a										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	1.89	3.30	1.54	0.59	0.71	0.22	0.93	0.85	0.45	5.76
Runoff (mm)	8.03	8.97	10.38	5.48	7.75	5.89	9.23	11.30	8.59	8.72
Salt load (kt)	0.67	1.94	0.85	0.21	0.57	0.10	0.43	0.29	0.18	3.25
Salinity (mg/L)	356	588	552	358	809	473	464	337	388	563
Groundwater discharge to stream zone (mm)	0.06	0.38	0.38	0.00	0.15	0.66	0.35	0.11	0.13	0.34
Baseflow (mm)	1.42	0.22	0.22	3.03	0.52	0.66	0.05	0.11	0.00	0.86
Average for 2060 b										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	1.84	3.06	1.47	0.61	0.64	0.20	0.85	0.80	0.43	5.42
Runoff (mm)	7.80	8.32	9.92	5.69	7.03	5.34	8.40	10.64	8.08	8.20
Salt load (kt)	0.66	1.04	0.42	0.24	0.23	0.08	0.34	0.28	0.15	1.83
Average annual salinity (mg/L)	360	340	285	392	352	425	397	345	343	338
Groundwater discharge to stream zone (mm)	0.00	0.05	0.06	-0.07	0.00	0.01	0.18	0.10	0.00	0.00
Baseflow (mm)	0.00	-0.04	-0.04	0.00	0.00	0.21	0.00	0.00	0.00	0.00

a annual mean for the period 2025 – 2035

b annual mean for the period 2055 – 2065

100% native vegetation

	Tweed River	Gnowergerup Brook	Mayanup	Dwalganup Brook	South Kulikup	Kenninup	Scotts Brook	Rylington	Kingston	Entire area modelled (Tweed/ Gnowergerup+ area outside)
Area (km^2)	236	377	148	108	91	37	101	75	53	661
Lake area (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 native forest (km^2)	236	377	148	108	91	37	101	75	53	661
Total 2007 native forest (%)	100	100	100	100	100	100	100	100	100	100
Total 2007 trees (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 trees (%)	0	0	0	0	0	0	0	0	0	0
Total 2007 cleared area (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 cleared area (%)	0	0	0	0	0	0	0	0	0	0
Total 2007 perennial pasture (km^2)	0	0	0	0	0	0	0	0	0	0
Total 2007 perennial pasture (%)	0	0	0	0	0	0	0	0	0	0
Average for 2030 a										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	1.87	3.15	1.44	0.58	0.67	0.21	0.91	0.84	0.45	5.55
Runoff (mm)	7.92	8.56	9.76	5.40	7.36	5.75	9.04	11.15	8.47	8.39
Salt load (kt)	0.59	0.97	0.40	0.22	0.22	0.08	0.28	0.24	0.14	1.69
Salinity (mg/L)	317	308	280	374	335	391	308	281	313	304
Groundwater discharge to stream zone	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Baseflow (mm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average for 2060 b										
Annual rainfall (mm)	590	551	551	580	548	521	576	621	568	568
Streamflow (GL)	1.83	3.00	1.42	0.61	0.64	0.19	0.84	0.79	0.42	5.36
Runoff (mm)	7.74	8.16	9.63	5.65	6.97	5.30	8.30	10.54	8.02	8.11
Salt load (kt)	0.63	0.99	0.42	0.24	0.23	0.08	0.28	0.24	0.15	1.76
Average annual salinity (mg/L)	345	331	295	400	362	433	336	302	345	327
Groundwater discharge to stream zone	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Baseflow (mm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

a annual mean for the period 2025 – 2035

b annual mean for the period 2055 – 2065

Scenario 15

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