water and land use change study



changes in hydrology and flow stress with land use change in south-west victoria

FINAL TECHNICAL REPORT • 7 JUNE 2005

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Preface

This report documents the second stage of the Water and Land Use Change study. It includes the final report on Stage 2^1 and some additional material on the effects of changes in land use and hydrology for flow stress in the study area's stream network. The later work, which was funded separately to the remainder of stage 2, has been integrated into the report. It provides a definitive assessment of how flow stress might change in response to the predicted land use and hydrologic changes in the region between 1990 and 2030.

¹ Sinclair Knight Merz (2005) Water and land use change study. Land use and hydrologic change in southwest Victoria. Consultancy report to the WatLUC Steering Committee.



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Document history and status

Revision	Date issued	Reviewed by	Approved by	Date approved	Revision type
Draft	22/10/04	Carl Daamen	Craig Clifton	22/10/04	
Draft 2	5/11/04	Carl Daamen, Rory Nathan	Craig Clifton	5/11/04	
Final	10/01/05	WatLUC Steering C'tee	Craig Clifton	10/01/05	
Final2	28/2/05		Craig Clifton	28/2/05	Inclusion of FSR results
Final technical report	10/5/05		Craig Clifton	10/5/05	Inclusion of preface

Distribution of copies

Revision	Copy no	Quantity	Issued to
Draft		11	WatLUC Steering Committee members
Draft 2		1 CD	Kylie Waller, GHCMA
Final		1 CD	Kylie Waller, GHCMA
Final2		1 CD	Kylie Waller, GHCMA
Final technical report		1 CD	Kylie Waller, GHCMA

Printed:	24 June 2005
Last saved:	10 May 2005 03:51 PM
File name:	D:\skm\wcms\wc02032\6_reporting\working report\watluc_stage2_fsr.doc
Author:	Craig Clifton, Carl Daamen & Avril Horne
Project manager:	Craig Clifton
Name of organisation:	Glenelg Hopkins Catchment Management Authority
Name of project:	Water and Land Use Change Study
Name of document:	Changes in hydrology and flow stress with land use change in south-west Victoria
Document version:	Final technical report
Project number:	WC02032



Executive Summary

The Water and Land Use Change (WatLUC) study addresses the challenges posed by land use and hydrologic change across south-western Victoria. Land use changed rapidly across this region during the late 1990s and the early years of the current decade. Although it has slowed in some sectors in recent years, the scale and nature of land use and vegetation change is so great that it has potential to transform the volume and quality of water moving through the region's landscapes. This may have profound implications for the region's water dependent ecosystems and for the way in which its water resources are managed.

The two major objectives of the WatLUC study were to:

- understand the dynamics of land use change in the region and develop some scenarios that reflect realistic land use change outcomes;
- to assess the impacts of these scenarios on water movement through landscapes and on the availability and quality of water for consumptive and environmental uses.

To date, there have been two stages in the WatLUC study. The first stage developed methods for determining the hydrologic impacts of land use and land use change and applied them in five case study catchments. This document reports on stage 2, in which the methods developed in stage 1 were applied to both the Glenelg Hopkins and Corangamite Catchment Management Authority (CMA) regions. It reports the nature and scale of hydrologic change associated with land use change scenarios and discusses some of the implications for water resources and flow-related stress in river systems.

The WatLUC project is primarily concerned with a sub-set of the land uses practiced in south-west Victoria, they include:

- Broadacre grazing with sheep and/or beef cattle
- Broadacre cropping
- Viticulture
- Plantation forestry using native hardwoods and Radiata pine
- Dairying
- Urban and commercial land use
- Rural residential land use
- Nature conservation through restoration of indigenous vegetation on private or public land

Ten land use change scenarios, incorporating different mixes of these land uses, were developed for the study area. The scenarios were derived from current land use mapping, trends in agricultural land use and commodity production, industry consultation and regional natural resource management policy documents. The combination of land uses in 1990 and 2003 was common to all scenarios. Individual land use combinations were developed for each scenario for 2010, 2020 and 2030 and for all of the 66 sub-catchments defined for the study area.



The most striking features of land use change since 1990 have been the expansions in broadacre cropping, dairying and Blue Gum plantations. Most change has been at the expense of broadacre grazing of sheep and beef cattle. Over the coming 30 years, broadacre cropping is the only major land use expected to continue to expand at close to its recent historical rate. The area of land given to dairying is likely to remain static and beyond the next few years there is only likely to be incremental expansion in the Blue Gum plantation estate. With some new hardwood plantation development, intensification in grazing operations and implementation of regional native vegetation restoration plans, there is likely to be a marked increase in the area of land covered by both non-woody and woody perennial vegetation. Increased water use associated with these changes is likely to lead to reduced recharge to shallow and deep aquifers and reduced flow in streams.

In this report the various land use change scenarios anticipate quite different land use outcomes, but this is not reflected in the calculated changes in catchment hydrology at the drainage basin scale. Changes in catchment hydrology with land use change were reflected in the progression over time of the base case scenario, which underpins most other scenarios. Large reductions in water yield were predicted for most basins, relative to 1990 levels. While differences between scenarios were modest at the scale of drainage basins, they were occasionally quite pronounced for individual subcatchments.



 Change in total water yield (1990-2030) for drainage basins in WatLUC study area and for each of the 10 land use change scenarios.



The WatLUC project predicts that there will be a significant reduction in the availability of surface water and groundwater resources as the result of land use changes that occurred during the last decade and that may take place over the next 30 years. The loss in the total surface water resource could amount to over 600 GL/y on a mean annual flow basis and the loss in groundwater to over 15 GL/y of annual average recharge to deep aquifer systems. These losses represent between 6 and 9% of total surface water flows generated within the study area and less than 1% of groundwater recharge, respectively. Around 50% of the surface water losses and over 90% of the loss in groundwater recharge would occur in the Glenelg drainage basin.

The upper catchments of the Glenelg, Barwon and Moorabool Rivers have large reservoirs that supply urban and rural water users. It is not expected that land use change will have a particularly marked effect on inflows to these storages. Land use change, particularly the increase in woody and non-woody perennial vegetation, is likely to be less pronounced in these areas than in many other places within the region.

In volumetric terms, the greatest impacts of land use change are likely to be experienced in the lower reaches of the Glenelg and Hopkins drainage basins. This reflects both the widespread perennialisation of vegetation cover that is anticipated and the large size of these basins. In percentage terms, the greatest reductions in water resource availability are likely to be experienced in the Portland Coast basin and in the upper reaches of the Glenelg, Hopkins and Lake Corangamite basins. Only in the Glenelg surface water basin is there likely to be any significant reduction in groundwater resource availability.

Total surface water use already exceeds the sustainable diversion limit (SDL) in the upper catchment areas of most drainage basins. Land use change is likely to considerably worsen flow related stress in these areas. The sum of current use and flow reductions due to land use change are predicted to increase to 10 times the SDL or more in some sub-catchments in Barwon, Lake Corangamite, Hopkins and Glenelg basins.

The flow regime of many streams in the WatLUC study area are already moderately to highly altered. Summer flows, particularly, are quite different to the natural flow regime in all but a few sub-catchments in the Barwon and Otway Coast drainage basins. Land use change will exacerbate these alterations to stream flow regime. However, while the largest change in flow regime are predicted to occur in sub-catchments in the Portland Coast and Glenelg River basins, the Moorabool River will continue to have the most highly altered flow regime. There was little difference in indices of flow stress between 2030 land use change scenarios.





Annual flow stress index under current conditions and 2030 land use change scenarios for drainage basins in the WatLUC study area. Flow stress index of 1 indicates natural flow regime: the index value falls with the degree of disturbance.

An empirical relationship development through WatLUC predicts that for every 10 percentage point increase in woody vegetation and perennial pasture or grassland cover within a subcatchment, total potential water yield would fall by around 20 and 2.8 mm/y, respectively. For each 1% increase in urban and commercial land uses, potential water yield would increase by about 2.6 and 3.5 mm/y, respectively. Changes in flow stress indices were less well correlated with land use change than changes in water yield. However, a similar empirical relationship predicted a 0.050 reduction in the annual flow stress index for each 10% increase in woody vegetation cover and a 0.015 increase in this value for each 1% increase in commercial land use. Urban and pasture and grassland land uses explained little of the difference in flow stress index.

The impact of land use change scenarios on the incidence of dryland salinity in the WatLUC study area has not been explicitly investigated. However, the estimated reductions in recharge in many of the regions' dryland salinity hot spots may help to slow the development of dryland salinity.

WatLUC has identified several 'hot spot' areas for hydrologic change. Further work is required in these areas to improve land use change predictions and to assess the extent and implications of hydrologic change. Hot spot areas include sub-catchments 49 and 51 in the Portland Coast basin and sub-catchments 58, 59, 65 and 66 in the Glenelg drainage basin. Sub-catchments in the Otway Coast, Barwon and Moorabool basins are not expected to be as adversely affected by land use



change. However some sub-catchments, particularly the upper and lower Moorabool River sub-catchments (#1 and 2), already experience very high levels of flow related stress.

Recommendations for further work to build on the data and analysis provided by this stage of WatLUC include the following:

- consider the implications of regional climate change projections on both land use change scenarios and catchment hydrology;
- evaluate the water quality implications of land use and hydrologic change;
- evaluate the implications of land use change for land and water salinity in regional priority areas.

It is recommended that the results of this stage of the study be communicated to government, industry stakeholders and the community throughout the region. Key natural resource management agencies should begin to consider the policy implications of the study.



1. Introduction

1.1 The Water and Land Use Change study

The Water and Land Use Change (WatLUC) study was developed to address the challenges posed by land use and hydrologic change across south-western Victoria. Land use changed rapidly across this region during the late 1990s and the early years of this decade. It was driven by a host of factors, including:

- technological innovation in the cropping industry;
- investment in new forestry plantations and vineyards;
- dairy deregulation;
- change in the relative terms of trade for various agricultural commodities;
- growth in lifestyle land uses along the coastal strip and within commuting distance of major population centres;
- growing environmental awareness.

The rate of change has slowed in some sectors in recent years (e.g. plantation forestry, dairying, vineyard development). However the scale and nature of land use and vegetation change is so great that it has potential to transform the amount and quality of water moving through the region's landscapes. This may in turn have profound implications for the region's water dependent ecosystems and for the way in which water resources are managed.

The study has been divided into several stages, as follows:

- Stage 1: Development and evaluation of methodologies in which the methodology for determining hydrologic impacts of land use and land use change were developed and applied in selected pilot study areas and in which current land use was determined and some initial future land use scenarios developed.
- Stage 2: *Evaluation of land use and hydrologic change in south-west Victoria* in which the approach developed during Stage 1 was applied to the Glenelg Hopkins and Corangamite Catchment Management Authority (CMA) regions of south-west Victoria to determine the nature of hydrologic change associated with updated land use change scenarios.
- Stage 3: Assessing the implications of hydrologic change in which the implications of changes in surface water flow and recharge to deep and shallow groundwater systems for water resource allocations, water flows, water quality and dryland salinity process will be considered.
- Stage 4: Sub-regional case studies in which the implications of land use and hydrologic change are explored at a sub-regional level, building on the initial analysis of the regional studies.



To date, only the first and second stages of the study have been commissioned. The first stage included the Glenelg Hopkins and Corangamite CMA regions in south-west Victoria and part of the South-East Catchment Water Management Board (CWMB) region in South Australia. The second and subsequent stages are only being undertaken in Victoria.

1.2 Study objectives

The objectives of the WatLUC study are to:

- develop a suite of realistic land use change scenarios for the region, that reflect current or potential drivers for land use change;
- understand the impacts of these scenarios on water movement through landscapes and on the availability and quality of water for consumptive and environmental uses;
- identify the scale of land use change required for particular beneficial or adverse effects;
- identify and gauge the significance of gaps in knowledge about hydrological response to land use and management practice;
- provide sub-regional information that supports land use and water allocation policy decisions.

1.3 WatLUC Stage 1

Stage 1 of WatLUC comprised three main "research" tasks: development of some preliminary land use change scenarios for the region, development of a method for assessing hydrologic change associated with these scenarios and applying this approach in five case study catchments in southwest Victoria and south-east South Australia. The modelling method and its results were progressively reviewed by the project Steering Committee and an independent scientific reviewer. Stage 1 was documented in an internal working report (Sinclair Knight Merz, 2003) and widely distributed community report (WatLUC, 2003).

This section provides a brief overview of the approach to stage 1 and its key outcomes.

Land use and land use change

A map of current land use was compiled for the entire study area, comprising the Corangamite and Glenelg-Hopkins CMA and South East CWMB regions. Data sets from a multiple sources and with varying scales, levels of currency and precision were used. New land use mapping was being undertaken in the two Victoria CMA regions at the same time as the land use map was being compiled.

Despite the recent rapid change in land use within the study area, broadacre grazing remains the dominant land use in the region. Forestry plantations, dairy pastures, cropping and nature conservation (including on-farm native vegetation) all occupy a similar area (7-9% of the region).



One of the key challenges of the first stage of the WatLUC study was to develop scenarios that represent possible future land use mixes for the region. These scenarios were based on the initial land use information, trends in land use change determined from the agricultural census, industry information on the area of land suited to certain uses and assumptions about growth in various industry sectors. A "base case" scenario was developed that represented future land use if current land use change trends were continued through to 2030. A series of high growth scenarios were also developed for each major industry sector (broadacre grazing, dairying, viticulture, forestry and cropping) and for a rapid expansion in revegetation and nature conservation on private land.

Land use change and water

A modelling approach was developed to enable the determination of how land use change affects the amount of water moving through landscapes. A unique and technically robust approach was developed. It incorporates:

- "paddock" scale soil water and solute balance modelling to estimate leakage to groundwater under various land uses or vegetation types;
- a model that predicts changes in catchment run-off with land use change;
- an analytical process that estimates surface water flows and recharge to deep aquifer systems in each sub-catchment.

The modelling approach is applicable at a sub-catchment scale, in keeping with both the "whole of region" focus of WatLUC and data limitations.

The land uses represented were plantation forestry, broadacre grazing on annual and perennial pastures, crops, viticulture and woodland (native vegetation). The WatLUC modelling approach was tested in five pilot study catchments during Stage 1 (Figure 1-1).

The anticipated extent of hydrological change associated with land use change scenarios varied greatly. Modelling predicted that the displacement of broadacre grazing by cropping and (in some parts of the study area) the upgrading of annual to perennial pastures would have little impact surface water flows. Hydrologic change was much greater where scenarios predicted large scale changes from broadacre grazing to irrigated agriculture or to woody perennial vegetation (plantations or native vegetation).

Project management and review

A steering committee, comprising representatives of public and private sector stakeholder organisations, was formed for the project. The steering committee played an important role, in terms of attracting funding for the study, confirming study direction and technical review of land use change scenarios, modelling methodology and pilot study results. They also provided important

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links to data sets, industry knowledge and landscape process understandings. The steering committee was assisted in their review of the study approach and preliminary results by an independent technical reviewer.



Figure 1-1 Stage 1 WatLUC study area and location of pilot study catchments

1.4 Report overview

This document is an internal reference document for WatLUC. It provides detailed descriptions of the methods used, the checks deployed to confirm them and the results obtained from modelling. It also provides a limited amount of discussion on the implications of the results. It is not intended for wider public distribution. A much briefer community report will be prepared for that purpose.

An overview of the contents of the main sections of this report is given below:

- *Chapter 2 Study area* a brief description of the WatLUC study area.
- *Chapter 3 Land Use and Land Use Change* a description of the current land uses in the study area, the methods used to develop the land use change scenarios and of the scenarios themselves.
- Chapter 4 Estimating Changes in Catchment Hydrology due to Land Use Change a description of the modelling approach applied in WatLUC, including the various validation procedures.
- Chapter 5 Changes in Water Yield with Land Use Change results from the WatLUC modelling approach are presented and described. The more detailed results are given in Appendix I.



- Chapter 6 Discussion a discussion of the methods, results and their implications.
- *Chapter 7* Conclusions a statement of the main conclusions of stage 2 of WatLUC.

Several appendices are included with the report and contain detail of the methods and results. A glossary (Chapter 10) provides definitions of terms that are used in this report, but may not be in common use.



2. Study area

2.1 Location

Stage 2 of WatLUC is being undertaken in the Glenelg Hopkins and Corangamite CMA regions of south-west Victoria (Figure 2-1). The region extends from Corio Bay and the Bellarine Peninsula in the east, to the South Australian border in the west and from the Great Dividing Range in the north to the Victorian coast in the south. The region occupies some 4 million ha, which is approximately 17% of the total area of the state.



Figure 2-1 Study area for the WatLUC project, showing towns, roads, CMA and local government boundaries

2.2 Climate

Annual rainfall across the study area ranges between about 550 mm in Geelong in the east of the region to over 1900 mm at Weeaproinah in the Otway Ranges. There are three broad climate zones, comprising: a zone of relatively high rainfall (>700 mm/y), extending up to 30 km inland, along almost the entire coastal strip; a zone of relatively low rainfall (<700 mm/y) that extends across areas of low topographic relief from Geelong almost to the South Australian border; and a zone of higher rainfall across the southern slopes of the Great Dividing Range.

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Figure 2-2 shows that average annual rainfall for each of the WatLUC sub-catchments. Rainfall ranges between 525 mm/y in the Hovell Creek sub-catchment, north-east of Geelong and 1475 mm in the Aire River sub-catchment in the Otways.



Figure 2-2 Average annual rainfall for south-west Victoria

Monthly average rainfall and maximum and minimum temperatures for four representative locations are plotted in Figure 2-3. Variation in average monthly temperature maxima and minima between the four locations is small. Maximum temperatures range between 10 and 27 °C and minimum temperatures between 3 and 14 °C.

Seasonal rainfall patterns are more variable across the region. Three patterns are evident in Figure 2-3 and from weather records for other locations (Lucas and Clifton, 1996). They are:

- Longer wet season locations on the southern slopes of the Great Dividing Range and in the Otways have consistently high rainfall totals between about May and October. The "wet" season is about one month shorter in the Otways.
- Shorter wet season the west of the study area (Casterton and Hamilton) has a shorter wet season than the more elevated parts. Wetter months are much more likely to be confined to winter than at either Ballarat or in the Otways.



• *Uniform rainfall* – rainfall is much more evenly spread on the drier, less elevated land in the east of the study area (e.g. Geelong). The wetter months are in spring, rather than winter.



 Figure 2-3 Average monthly rainfall, and maximum and minimum temperature for representative locations in the WatLUC study area. (Source: Bureau of Meteorology)

2.3 Physiography

The four main physiographic units in the WatLUC study area are described below (from Lucas and Clifton, 1996).

• *Western Victorian Uplands* – this unit comprises the Great Dividing Range, Grampians and the Dundas and Merino tablelands. It forms a near contiguous unit of mountains, ridges, plateaux and tablelands across the north of the study area. A small outlier of this region occurs in the



Glenthompson area. Most of the uplands lie between about 200 and 500 m above sea level, with several mountains in the Grampians and Mt Cole Range reaching elevations of over 800 m. The uplands of the Great Dividing Range and Grampians mostly comprise Palaeozoic rocks of sedimentary, volcanic, granitic and metamorphic origin. Lower slopes of these uplands comprise outwash materials. The Dundas and Merino tablelands have extensive laterite cappings over weathered volcanic and sedimentary materials, respectively, and are dissected to varying depths by streams.

- Western Victorian Volcanic Plain the plain lies to the south of the uplands and largely comprises undulating plains of quaternary age basalt. Some lava flows extended into upland valleys in the north-east of the study area. The plains are mostly below 200 m in elevation. They are marked by numerous eruption points, some rising to 300-500 m. Most areas have not been deeply weathered. In parts, the plain is poorly drained and comprises lacustrine complexes of lakes, wetlands and lunettes.
- South Victorian Coastal Plains the unit consists of a variety of landforms, including ridges and flats, dissected plains, sand and clay plains and barrier complexes. The ridges and flats sub-division was formed by the retreat of the sea during the Pliocene and Pleistocene. The dissected Port Campbell plain comprises limestone overlaid with littoral or terrestrial sediments. Barrier complexes cover coastal areas in the west of the study area.
- South Victorian Uplands this unit consists of the Otway Range and Barabool Hills. The two
 areas are part of the same geological formation, however intervening land is covered by thin
 Tertiary sediments. The geology is Cretaceous age sediments. The main landforms are
 plateaux, ridges and deeply dissected hills. Elevation ranges from sea level on the Otway coast
 to over 600 m.

2.4 Hydrology

The WatLUC study area includes seven main drainage basins (Figure 2-4):

- *Moorabool* the catchment of the Moorabool River and the Hovell Creek (which drains to Corio Bay. Average surface water flows are 200 GL/y.
- Barwon the catchments of the Barwon and Leigh Rivers. Average surface water flow is approximately 840 GL/y.
- *Corangamite* the catchment of Lake Corangamite. Average surface water flows are 516 GL/y.
- Otway Coast catchments of the streams draining to the coast from the Otway Ranges. Average surface water flows are approximately 1050 GL/y.
- *Hopkins* the catchment of the Hopkins River and the Fiery and Mt Emu Creeks. Average surface water flows total over 2100 GL/y.



- *Portland Coast* catchments of streams draining directly to the coast in the Portland-Warrnambool area. Average surface water flows are approximately 390 GL/y.
- *Glenelg* the catchment of the Glenelg and Wannon Rivers. Average surface water flow through the catchment is almost 3280 GL/y.

Streams in the Moorabool, Barwon and Glenelg basins are highly regulated. A very high proportion of the surface water flows are diverted for urban and agricultural uses. In contrast, the high yielding streams flowing to the Otway coast are generally unregulated, with relatively small diversion volumes.

The WatLUC study area is dotted by a large number of lakes and smaller wetlands. The largest of these is Lake Corangamite, with an area of 23,000 ha.



Figure 2-4 Drainage basins, major streams and lakes in the WatLUC study area

Appendix A provides further information on the water resources and hydrology of the study area. It includes maps indicating mean annual flow at a sub-catchment level, the sustainable (winter) diversion limit for each sub-catchment, the current level of flow usage and winter, summer and annual flow stress ranking (FSR) indices.



2.5 Hydrogeology

The hydrogeology of the study area is described by Dahlhaus *et al.* (2002a;b), using the groundwater flow systems (GFS) framework of Coram *et al.* (2000; 2001). The flow systems are described in the context of dryland salinity and its management and typically address relatively shallow aquifers. Three broad classes have been defined, as follows:

- Local groundwater flow systems are fully contained within small catchments with a
 horizontal scale of up to 5 km. They can respond relatively rapidly to changes in water
 balance. The area contributing to groundwater discharge is both relatively identifiable and
 relatively small. The water table surface is typically a subdued reflection of the land surface.
- Intermediate groundwater flow systems operate within much larger catchments than local systems (typically up to 20 km). They have a greater storage capacity and take longer to 'fill' following changes in land use that result in increased recharge. The water table surface may not reflect surface topography.
- Regional groundwater flow systems operate over large distances (greater than 50 km). These
 systems tend to respond slowly to changes in land use or management. The areas contributing
 to groundwater discharge are generally large.

Eighteen GFS have been identified for the Glenelg Hopkins region (Dahlhaus *et al.*, 2002a) and 17 for the Corangamite region (Dahlhaus *et al.*, 2002b), with a total of 27 different systems across the entire WatLUC study area.

The dominant groundwater flow systems in the study area are the generally intermediate to regional scale systems associated with geologically recent volcanic activity, that formed the volcanic plains of the western district and central highlands and the region's stony rises and scoria cones. Local flow systems are associated with the various upland areas in the south-east and north of the study area (e.g. Grampians, Otways) and the scattered areas of Quaternary age alluvial deposits. Coastal plain areas in the south and west of the region are underlain by regional scale limestone and sand plains flow systems.

Groundwater flow does not necessarily follow surface water catchments in some of the regional scale flow systems. There is an extensive network of deep leads in the north of the region, which sit beneath the central highlands volcanic plains. They drain to the north, across the current surface water divide and into the Murray-Darling Basin.

2.6 Native vegetation

The native vegetation of the WatLUC study area is extremely diverse. Around 200 EVCs (ecological vegetation classes) have been identified. Loss of native vegetation cover since European settlement commenced in the early 1800s has been extensive (Figure 2-5). Only about 19% of the original native vegetation cover remains. Around one quarter of the EVCs have been



reduced to 5% of their pre-1750 area or less. Grasslands and grassy woodlands are the worst affected by clearing and agricultural land use, with about 1 and 6%, respectively, of the pre-1750 area of these types of EVCs remaining.



 Figure 2-5 Native vegetation cover in the WatLUC study area. Blue areas are lakes and wetlands. Green areas support native vegetation. Red areas are hardwood and softwood plantations. Uncoloured areas are cleared land that has been mapped as not supporting native vegetation.

Most remnant native vegetation is located in large blocks of public land in the Otways, Grampians, in the far west of the region and in upland areas south of Ballarat (Figure 2-5). The western Victorian volcanic plain, which occupies much of the land between Geelong and Hamilton, supports few substantive tracts of native vegetation.

2.7 Natural resource management issues

Regional Catchment Strategies for the Glenelg Hopkins and Corangamite CMA regions (CCMA, 2003a; GHCMA, 2002a) outline the key regional natural resource management challenges faced in the WatLUC study area. The major issues include:



- Biodiversity decline as noted above, native vegetation coverage has been severely depleted across south-west Victoria. Around 19% of the original native vegetation cover remains, with grasslands and grassy woodlands being the most severely depleted types. Loss of native vegetation habitat is also associated with a decline in populations of dependent native fauna.
- *Competition for water* the surface water and groundwater resources of many parts of the study area are heavily utilised for urban, industrial and agricultural uses (Appendix A). The level of utilisation is such that the Victorian government is proposing to place a cap on further diversions in some catchments (Government of Victoria, 2004). Population growth, intensification of agriculture and growth in dams associated with rural residential land use will all place increasing demand on streams that are often already highly "stressed".
- Land use change this study was proposed because of concerns that the rapid pace of land use change in the region had potential to affect water resources and water dependent ecosystems. Poorly managed land use change also has potential to lead to loss of native vegetation, through clearing, cultivation and rural residential or urban development. It can also contribute to the spread of pest plant and animal populations, which impact on biodiversity and agricultural production.
- Dryland salinity dryland salinity is pervasive across many parts of the study area (NLWRA, 2001; CCMA, 2003b; GHCMA, 2002b). It has developed in response to changes in land use and vegetation cover with settlement, clearing and agricultural development. It affects agricultural production, water quality, river health and biodiversity.
- Water quality decline water quality in many of the study area's streams is poor and/or declining (Victorian Catchment Management Council [VCMC], 2002). Salt, sediment and nutrients such as nitrogen and phosphorus are the main contaminants. Although this reflects natural conditions in some cases (e.g. naturally saline streams and lakes), water has generally been contaminated as the result of human activity. Urban stormwater and waste water, erosion and nutrient run-off from agricultural land and the development of secondary (human induced) salinity all contribute.
- Declining river health loss of vegetation cover, altered flow regimes and loss of water quality all contribute to declining river health across the study area. With the exception of streams in the Glenelg and Otway coast drainage basins, less than 10% of the length of streams in the region are in good or excellent condition (Department of Natural Resources and Environment, 2002).
- *Soil health* there are several significant soil health issues in the study area (VCMC, 2002), including water erosion, soil structure decline and induced acidification.

2.8 Communities

The population of the study area is approximately 425,000 (CCMA, 2003a; GHCMA, 2002a). Around 75% of the population live in the Corangamite CMA region and most of them in the two



major population centres, Geelong and Ballarat. The population is growing rapidly in these major centres, on the Bellarine Peninsula and in other nearby coastal areas. There is increasing expansion of rural residential and lifestyle land use around the major centres, along the coast and in areas within easy reach of it.

The Glenelg Hopkins CMA region is more rural than the Corangamite CMA region. Being more remote from Melbourne and other major population centres (apart from the far north east of the region, which is close to Ballarat), it is less subject to rural residential and lifestyle land uses. The population is actually expected to decline over the coming 20 years (GHCMA, 2002a).

The WatLUC study area includes parts of 18 local government areas (Figure 2-1).



3. Land Use and Land Use Change

3.1 Land uses of interest to WatLUC

The WatLUC Steering Committee identified a set of land uses of interest to them. This was expanded somewhat at the commencement of Stage 2 to provide complete coverage of the study area. The land uses of primary concern to the Steering Committee include:

- Broadacre grazing grazing activities associated with wool, sheepmeat and/or beef cattle enterprises. Grazing is carried out on a range of pasture types, including native grasslands, unsown pastures, rainfed sown annual and perennial pastures.
- Dairying grazing activities associated with dairy production. Grazing is typically carried out
 on sown annual and perennial pastures, some of which are irrigated.
- Broadacre cropping crop production using cereals, oilseeds and grain legumes. Cropping
 may be carried out conventionally or on the increasingly widely used raised beds.
- Plantation forestry using hardwood and softwood species. Blue Gum (Eucalyptus globulus) is the main species of hardwood planted in the region and Radiata Pine (Pinus radiata) the main softwood species. There are significant areas of Sugar Gum (E.cladocalyx) plantation across the study area and the species is being promoted for farm forestry in lower rainfall areas that are not suited to Blue Gums.
- *Viticulture* grape production, typically on irrigated vineyards.
- Nature conservation establishment and/or maintenance of native vegetation communities on public and private land. This class includes forestry production in native forests, as this is taken as a fixed land use from a hydrological perspective.
- *Rural residential land use* low density residential land use, typically in areas previously used for agriculture.
- *Intensive uses* urban areas in cities and towns, including residential, commercial and industrial land uses.
- Lakes and other water bodies.

While these are not the only land uses practiced in the study area (section 3.3), they account for almost all of the land area. They also provide a basis for integrating other minor land uses to ensure complete coverage of the study area.

3.2 Land use mapping

Land use mapping in Australia in generally undertaken according to the Australian Land Use Mapping (ALUM) framework (Bureau of Rural Sciences [BRS], 2002). While the framework provides a useful, systematic approach to land use classification, the land uses it defines need to be



reinterpreted in a study such as this. The ALUM framework classifies land use based on the level of intervention in the landscape and the principal and ancillary uses of a parcel of land. These classes are not always meaningful from a hydrological perspective and in some cases do not help in distinguishing land uses of interest to the study (e.g. broadacre grazing and dairying).

Table 3-1 matches the land uses of interest to this study with the various ALUM land use classes. ALUM has a three level hierarchy. The first level includes six primary land use classes, as follows (BRS, 2002):

- 1. Conservation and natural environments Land used primarily for conservation purposes, based on the maintenance of the essentially natural ecosystems present.
- 2. Production from relatively natural environments Land used primarily for primary production with limited change to the native vegetation.
- 3. Production from dryland agriculture and plantations Land used mainly for primary production, based on dryland farming systems.
- 4. Production from irrigated agriculture and plantations Land used mostly for primary production based on irrigated farming.
- 5. Intensive uses Land subject to extensive modification, generally in association with closer residential settlement, commercial or industrial uses.
- 6. Water Water features.

The match of WatLUC land uses and ALUM land use classes in Table 3-1 is given at the highest, most inclusive level possible.

At the time of the first stage of the study there was no detailed and comprehensive land use coverage for the Victorian sections of the study area. Several land use mapping projects were under way, but their products were not available to the study. Information on land use for these areas was therefore compiled from several sources, including a BRS 1:1,000,000 land use coverage, National Forest Inventory (NFI) plantations data, various Victorian government land use related data sets (e.g. on distribution of public land, native vegetation cover) and the Australian Bureau of Statistics (ABS) agricultural census.

New land use mapping data for the study area was published by Primary Industries Research Victoria (PIRVic) during the gap between the first and second stages of the WatLUC study. Mapping was based on the Australian Land Use Mapping framework (BRS, 2002) and was undertaken at 1:100,000 scale. The Glenelg Hopkins and Corangamite CMA regions were mapped separately.



• Table 3-1 ALUM land use classifications associated with WatLUC land uses.

WatLUC land use	ALUM land use class			
Broadacre grazing	2.1 Grazing natural vegetation; 3.2 Grazing modified pastures;			
Dairying	3.2 Grazing modified pastures; 4.2 Irrigated modified pastures			
Broadacre cropping	3.3 Cropping; 4.3 Irrigated cropping;			
Plantation forestry:	3.1 Plantation forestry; 4.1 Irrigated plantation forestry;			
 Hardwoods 	3.1.1 Hardwood production; 3.1.3 Other forest production; 4.1.1 Irrigated hardwood production; 4.1.3 Irrigated other forest production;			
 Softwoods 	3.1.2 Softwood production; 4.1.2 Irrigated softwood production;			
Viticulture	3.4.4 Vine fruits (and other forms of perennial horticulture 3.4); 4.4.4 Irrigated vine fruits (and other forms of irrigated perennial horticulture 4.4);			
Nature conservation	1. Conservation and natural environments; 2.2 Production forestry, 3.1.4 Environmental;			
Rural residential land use	5.4.2 Rural residential			
Intensive land uses:				
 Commercial 	5.1 Intensive horticulture; 5.2 Intensive animal production, 5.3 Manufacturing and industrial; 5.5 Services; 5.6 Utilities; 5.7.1 Airports and aerodromes; 5.7.4 Ports and water transport; 5.7.5 Navigation and communication; 5.9 Waste treatment and disposal (except 5.9.5);			
 Urban 	5.4.1 Urban residential			
 Transport 	5.7.2 Roads; 5.7.3 Railways			
 Mines & quarries 	5.8 Mining			
Lakes and other water bodies	5.9.5; Sewage; 6. Water;			

3.3 Current land use in south-west Victoria

A consolidated map for the study area is given in Figure 3-1. It is a compilation of the two PIRVic data sets, with the ALUM classifications adjusted to reflect Table 3-1. A summary of the breakdown in land use between the various WatLUC land uses at the study area scale is given in Table 3-2.

Table 3-2 WatLUC study area: 2003 land use

WatLUC land use	Area (km ² & %)	WatLUC land use	Area (km² & %)	
Commercial	228 (0.6%)	Cropping	2,680 (6.7%)	
Hardwood plantation	729 (1.8%)	Livestock grazing	26,112 (65.0%)	
Mining	80 (0.2%)	Nature conservation, native	6,649 (16.6%)	
Orchard ¹	4 (0.0%)	production forests, environmental		
Rural residential	263 (0.7%)	Softwood plantation	1,177 (2.9%)	
Transport	1,162 (2.9%)	Unclassified	23 (0.1%)	
Urban	268 (0.7%)	Vegetables ¹	58 (0.1%)	
Viticulture	6 (0.0%)	Water	725 (1.8%)	

1. Additional land use to enable complete coverage of region





Figure 3-1 2003 land use map for WatLUC study area

Livestock grazing is clearly the major land use across the entire study area, occupying 65% or over 26,000 km². Land use mapping cannot be used to discriminate between broadacre grazing and grazing by dairy herds. ABS Agricultural Census data has been used for this purpose (section 3.4).

Nature conservation, which includes all land supporting native vegetation, is the second most significant land use occupying almost 17% of the study area. Cropping is the third most significant land use and, at the time of land use mapping, accounted for 6.7% of the study area. Approximately 4.7% of the region (or 1,900 km²) is covered by either hardwood or softwood plantations².

3.4 Historical changes in land use

Future land use scenarios are in part based on historical trends in land use derived from ABS Agricultural Census data. This section describes the method of analysis of ABS statistics and the resulting information on the breakdown of agricultural land uses between various classes and the rates of change in land use across the region.

SINCLAIR KNIGHT MERZ

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² Sugar gum, pine and cypress windbreaks were also included in these classes by the producers of the land use map.

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ABS Agricultural Census data

The Agricultural Census (AC) is a periodic census of all primary producers meeting a minimum value of agricultural production of \$5000. Among other things, it collects data on the area of land under various uses, the number of livestock carried and sold and the gross value of agricultural production.

The census is reported at a statistical local area (SLA) level (Figure 3-2). In Victoria, SLAs correspond to either entire local government areas or parts thereof. Where the boundary is only part of a current local government area, it is normally based on the boundaries prior to the round of council amalgamations that occurred during the 1990s. Data is reported in the SLA in which the landholder resides and not the SLA of the individual or various landholdings.

SLA boundaries change from time to time, as does some of the information collected.



Figure 3-2 Statistical local areas in WatLUC study area. Note that some small SLAs around Geelong and Ballarat are not labelled.

Stage 1 of WatLUC only used data from the 1997 census. Since completion of that stage, data from the 2001 census has become available. Data from previous censuses (back to 1990) was also



sourced³ and included in the assessment of historical trends in land use. Data from non-census years is based on supplementary information collected by the data supplier¹.

Data analysis

Agricultural census statistics were compiled for each SLA (Table 3-3) so that information relevant to the main WatLUC land uses could be extracted. Due to inconsistencies in the census, not all relevant data were collected in each year. The infrequent collection of some data (e.g. on area irrigated, area of sown pasture) meant that although information was available, it could not be used in determining trends in land use change.

Areas of pasture under various forms of livestock grazing were calculated using some simple assumptions about the equivalence of animal feed requirements and the stocking capacity of pastures. Raw stock numbers were converted to dry sheep equivalents (dse) based on assumed values of dse/head of stock (from Beattie and Holden, undated). It was assumed that dairy, beef and sheep pastures would, on average, support similar stocking rates in terms of dse/ha. Since dairy pastures are likely to be more intensively fertilised and grazed, this assumption will most likely overstate the area of dairy pasture⁴.

The total area of holding reported in SLAs varied from year to year. This issue was corrected for in determining the land use change scenarios (section 3.5).

Data for small urban and peri-urban SLAs were generally combined to provide more meaningful results. This helped to eliminate problems with relocation of Census respondents, differences between residential address and property location and changes in SLA boundaries. The combined SLAs included:

- Ballarat Ballarat C, Ballarat Inner, Ballarat North, Ballarat South;
- *Geelong* Bellarine Inner, Corio, Geelong, Geelong West, Greater Geelong, Greater Geelong
 C, Newton, Queenscliffe;
- Moyne South Moyne South, Warrnambool;
- Southern Grampians Southern Grampians Balance, Southern Grampians Hamilton;
- Surf Coast Surf Coast East; Surf Coast West

³ From Neil Clark and Associates, Agricultural Consultants, Bendigo.

⁴ However, since dairy pastures are generally represented in a similar way to broadacre pastures in the modelling, this assumption is unlikely to substantively affect estimates of hydrologic change with land use change.



Table 3-3 ABS Agricultural Census data used in WatLUC study and data availability over period of record.

		Data availability ¹											
Data	Derivation ²	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Total area of holding		~	~	~	~	~	✓	~	~	~	~	~	✓
Cropping													
Crops for hay	Crops & pasture for hay – pasture for hay		~	~	~	~		~	~	~	~	~	~
Total crops	Legumes + canola + crops for hay + cereals	~	~	~	~	~	~	~	~	~	~	~	~
Pastures													
Irrigated pastures ³									✓				✓
Sown pasture ³								✓	✓				✓
Pasture	Total area of holding – crops – total horticulture	~	~	~	~	>	~	~	~	~	~	~	>
Horticulture													
Total vegetables	Potato seed + vegetables					✓	✓	✓					
Grapes		~	~	✓	~	~	~	✓	✓	~	✓		✓
Orchards		~	~	✓	~	~	~	~	~	~		~	~
Total horticulture	Grapes + orchards + nurseries + cut flowers + turf + total vegetables	~	~	~	~	~	~	~	~	~	~	~	~
Livestock													
Sheep numbers (dse)	Sheep numbers/1.2 dse/head	~	~	~	~	~	~	~	~	~	~	~	~
Dairy cattle numbers (dse)	Dairy cattle numbers/ 15 dse/head	~	~	~	~	~	~	~	~	~	~	~	~
Beef cattle numbers (dse)	Beef cattle numbers/9 dse/head	~	~	~	~	~	~	~	~	~	~	~	~
Pasture adjusted for I	ivestock ⁴												
Sheep	Sheep dse/total livestock dse × total pasture area	~	~	~	~	~	~	~	~	~	~	~	~
Dairy cattle	Dairy cattle dse/total livestock dse × total pasture area	~	~	~	~	~	~	~	~	~	~	~	~
Beef cattle	Beef cattle dse/total livestock dse × total pasture area	~	~	~	~	~	~	~	~	~	~	~	~
Broadacre grazing	Sheep + beef cattle	~	✓	✓	~	✓	~	~	~	✓	~	~	~

1. ✓ indicates data available; blank indicates data not available

2. Derivation – blank indicates data obtained directly from AC, otherwise cell contents indicates how data calculated.

- 3. Data not used.
- 4. Assumes sheep, dairy and beef cattle pastures support similar dse/ha.

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Regression analysis was used to calculate the linear rate of change in each of the attributes listed in Table 3-3. Correlation coefficients (r^2) indicated that in many cases there was a strong linear trend with time. Appendix B provides examples for five SLAs with contrasting land use patterns: Ararat (a sheep grazing and broadacre area), Colac Otway South (a predominantly dairying area), Glenelg North (a predominantly sheep grazing area) Glenelg South (a mixed dairy and broadacre grazing area) and Golden Plains (a predominantly sheep growing area, located between the region's two main population centres, Ballarat and Geelong).

Trends in agricultural uses for the whole study area are also shown in Figure 3-3. Between 1990 and 2001 there was a very strong trend of dairying and cropping displacing broadacre grazing. The total area of holdings reported has been increasing consistently, suggesting that increasing numbers of sub-commercial operations are being included in the agricultural census.



Agricultural land use area (ha)	Rate of change in land use (ha/y)	R ²
Total area of holdings	10,231	33.6%
Area of cropping	12,078	83.1%
Area of dairy pastures	29,946	91.9%
Area of broadacre grazing (sheep and beef cattle)	-31,803	88.6%

Figure 3-3 Trends in agricultural land uses from Agricultural Census data



The data indicates that losses of land to broadacre grazing have generally been from sheep rather than beef cattle enterprises. The area of land grazed by beef cattle is estimated to have increased slightly between 1990 and 2001. Expansion in dairying appears to have slowed from about 1998 (Figure 3-3).

All forms of horticulture occupy a very small proportion of the total area of land under commercial agriculture. Trends in horticulture cannot be plotted on the same axes as those in other forms of agriculture.

3.5 Developing land use change scenarios

Definition of the scenarios of interest

Land use change scenarios are being used in WatLUC to explore the potential hydrological impacts of land use change. The scenarios represent the combination of land uses under a range of industry and demographic change outlooks and government policy and program settings.

Land use scenarios were forecast for 2010, 2020 and 2030 and backcast to 1990 on the basis of ABS statistics, industry consultation⁵, published industry information and CMA or government policy documents. Backcasting was undertaken so that hydrologic modelling would reflect recent changes in land use, particularly in forestry and cropping. Ten such scenarios have been developed for the Stage 2 of the study, as follows.

Base case – the extent of change in land use is based on industry estimates of the likely rate of change or future extent of relevant land uses, as follows:

Dairying	Industry representatives found it difficult to predict the outlook for dairy. They suggested that the area of land under dairying would remain relatively static over the outlook period. A base rate of expansion of 1% of the 2003 area (p.a.) was used.
	In areas where the AC indicated dairying was declining, the area under dairy pasture continued to decline (to zero area if necessary).
Cropping	Cropping industry representatives were upbeat about the prospects for cropping within the region. Some representatives foresaw no reason why cropping would not continue to grow at its historical rate, others were a little more circumspect. The adopted rate of change for cropping in the base case was 75% of the rate from the AC, relative to the 2003 area. Cropping was increasing in all areas. The 1990 crop scenario was based on 1990 AC data.
Softwood plantations	The softwood industry is a mature one, with very slow rates of change. 2003 area estimates were based on PIRVic land use mapping (Figure 3-1). A rate of 0.5% growth relative to the 2003 area was used, where softwood plantations were already present. No new plantation areas were introduced in areas were softwood plantations were not present in 2003.

⁵ Industry consultation with representatives of the dairy, cropping and forestry industries.



Hardwood plantations	Representatives of Blue Gum plantation companies considered that expansion in the Corangamite region was at about its limit on the basis of land prices and competition from other uses. They foresaw better growth opportunities in the Glenelg Hopkins region. Their estimate was that the industry would grow to about 18,000 and 105,000 ha, respectively, within the next few years. For convenience, these areas were assigned to 2010. The area under Blue Gums was then assumed to grow at 0.5% of this area at locations that already supported Blue Gum plantations.
	It was assumed that in 1990 there were no Blue Gum plantations.
	The use of low rainfall farm forestry species, such as Sugar Gum is being advocated by DPI and farm forestry groups. Growth in this land use of the order of 600 ha/y across relevant parts of the region was assumed (lower rainfall, basalt plains country). It was assumed that this land use was incorporated into 2003 (and 1990) estimates of hardwood plantation.
Revegetation	Native vegetation plans for the two regions (CCMA, 2003c; GHCMA, 2000) propose substantive investment in new conservation plantings, mostly on private land. The base case revegetation scenarios assume that the optimistic targets set in the native vegetation plans will be achieved by 2050, rather than 2030 as proposed. The targets adopted for the scenarios are that all endangered EVCs be increased to 10 or 15% of their pre-1750 coverage, for the Corangamite and Glenelg-Hopkins regions, respectively.
	Vegetation cover was backcast to 1990 assuming that the rate of change was 5% of the annual change from 2003.
	It is assumed that revegetation on rural residential land will not be to EVC and that any such revegetation would be additional to that required to achieve regional native vegetation restoration targets.
Horticulture	Non-wine grape horticulture continues to expand or contract at historical (AC) rates. Estimates of rates of change in viticulture are based on industry estimates of excess production capacity in cool climate wines for much of the next decade (McGrath-Kerr Business Consultants, 2003; Sinclair Knight Merz, 2004a). The adopted rate of change was the historical trend or 3% increase relative to the 2003 area, whichever was least (Appendix C).
Rural residential land use	The amount of rural residential land use and the rate of change varies according to proximity to Melbourne and the main regional population centres. Three zones of rural residential growth were identified (Figure 3-4):
	 High growth – areas with a relatively large amount of rural residential land and high likely growth rate. Growth at 4 times the low growth rate (relative to 2003 area).
	 Moderate growth – areas with moderate amounts of rural residential land, and less growth potential because they are more remote from major regional centre. Growth at 2 times the low growth rate (relative to 2003 area).
	 Low growth – areas with little or no rural residential land and few growth prospects. Growth at 2% p.a. relative to the 2003 area.
Urban and commercial land uses	As above, except that the low growth rate of expansion is 0.5%
Transport	Transport is a major land use across the region (Table 3-2). The assumed growth rate is 0.05% p.a., relative to the 2003 area.
Broadacre grazing	The rate of change, before adjustment for non-agricultural land uses continues at the historical trend.


Following the application of the above change rates, agricultural land uses were adjusted to account for expansion or contraction in other land uses.



- Figure 3-4 Growth rate zones for rural residential, urban and commercial land uses
- Historical changes in agricultural land uses continue at the historical rate prior to adjustment for non-agricultural land uses. Non-agricultural and horticultural land uses change at the base rate.
- *High cropping* this scenario is based on an optimistic view of the cropping industry.
 Expansion progresses at 125% of the 1990-2001 rate. Non-agricultural and horticultural land uses change at the base rate, with agricultural land uses adjusted to reflect these changes.
- *High dairy* this scenario is based on a relatively optimistic view of the dairying industry. Expansion progresses at 5% p.a. relative to the 2003 area, compared with 1% for the base case. Non-agricultural and horticultural land uses change at the base rate, with agricultural land uses adjusted to reflect these changes.
- *High forestry* under this scenario, the industry expands beyond what are currently considered to be the limits to growth. Under this scenario, the Blue Gum plantation estate would increase to a total of 150,000 ha in the Glenelg Hopkins CMA region and about 25,000 ha in the Corangamite region by 2020. Growth continues beyond that time at 0.5% p.a. relative to the 2020 plantation area. Softwood plantation area grows at 1% p.a. relative to 2003, which is



double the base case rate. Low rainfall farm forestry expands at 900 ha/y in the relevant parts of the study area.

- *High revegetation* under this scenario the Corangamite and Glenelg Hopkins CMAs' targets for restoration of endangered EVCs are achieved within the nominated 2030 timeframe.
- *IUCN* this is a lower change revegetation scenario, in which vegetation restoration proceeds to achieve 5% cover for all endangered EVCs, relative to their pre-1750 distribution, a target consistent with that of the International Union for the Conservation of Nature (IUCN).
- *High rural residential* the low rate of growth for rural residential land is 3% p.a., relative to the 2003 area, compared with 2% for the base case.
- *High grape* where the area of land under vineyards expands at 10% p.a.
- Broadacre grazing –this scenario reflects relatively buoyant conditions in broadacre livestock grazing enterprises. Broadacre grazing is not displaced by dairying (from 2003) and the rate of expansion in cropping is half the rate indicated by the AC. The rate of forestry expansion is curtailed to 0.1% for Blue Gum and softwood plantations (post 2010) and at 200 ha/y for Sugar Gum.

Land use and land use change trend data adjustment

The hydrologic impact assessment is being undertaken on a sub-catchment basis. The 2003 land use map was intersected with the WatLUC sub-catchment layer to provide a report of the initial mix of land uses in each sub-catchment. AC data were used to divide livestock grazing land uses into dairying and broadacre grazing. Since the sub-catchment boundaries do not match with those of the SLAs, the two were intersected to determine the proportion of each SLA in each sub-catchment. Grazing land uses were allocated on the assumption that they were evenly distributed across the sub-catchment and SLA.

The relevant scenario trends in land use were applied to each sub-catchment. They were applied to the whole sub-catchment for the non-agricultural land uses. Where they were used, relevant trends from AC data were applied to each of the SLAs in a sub-catchment. Again it was assumed that these trends could be applied uniformly across the relevant areas.

Several other data adjustments were required before the land use mix for each time period and scenario were finalised, as follows:

 adjustment of agricultural census data (trends and area estimates) to account for differences between the area of agricultural holding in an SLA and the total area of agricultural land use in the SLA. Census data were corrected to give equivalent total areas of agricultural land use in each sub-catchment;



- correction of negative agricultural land use areas. In some instances, the automated application
 of land use change trends produced negative land use areas. When this occurred, the offsetting
 agricultural land use (dairy/broadacre grazing, livestock grazing/cropping) was adjusted
 downwards to maintain the same total area;
- adjustment of agricultural land uses in each sub-catchment to account for changes in non-agricultural land uses. Changes in non-agricultural land use were offset by change in agricultural uses. The final gross agricultural land use area for each sub-catchment adjusted to reflect change in non-agricultural use. The residual area was then allocated to broadacre grazing, dairying and/or cropping according to the proportion prior to this non-agricultural land use adjustment.
- adjustment back to the same sub-catchment area. Since there was a general trend for the area
 of agricultural holdings to increase over time (Figure 3-3), the land use change trends between
 different land uses did not entirely off set each other. Land use changes were therefore
 expressed as a percentage of the total area rather than in hectares.

Vegetation cover in rural residential land

Since there is a substantial hydrologic difference between land covered by trees and that covered by pasture, it was necessary to assign a cover type to all rural residential land. Pasture land was further sub-divided into long and short growing season perennial pastures and annual pasture, again because of hydrological differences (see Chapter 4). Cover types were assigned arbitrarily, based on the length of growing season (Figure 3-5) and assumptions that revegetation on rural residential land would be incremental and a relatively low rate and that the perennial composition of pastures would decline over time. Coastal sub-catchments were assumed to have longer growing seasons and that rural residential land would support some long growing season perennial pastures. It was assumed that all residual native vegetation on rural residential land was included in land use mapping as native vegetation and hence revegetation percentage in 1990 and 2003 was set to zero. The cover types assigned are given in Table 3-4.

	Coa	astal long-grov	ving season are	Shorter growing season areas			
Year	Revegetation	LGS ² perennial	SGS ³ perennial	Annual pasture	Revegetation	SGS ³ perennial	Annual pasture
1990	0%	20%	40%	40%	0%	40%	60%
2003	0%	20%	40%	40%	0%	40%	60%
2010	5%	5%	40%	50%	5%	30%	65%
2020	10%	5%	30%	55%	10%	20%	70%
2030	14%	5%	24%	57%	15%	10%	75%

Table 3-4 Mix between revegetation and pasture cover¹ for rural residential land

1 Cover is % of total area under rural residential land use.

2 LGS – long growing season perennial pasture 3 SGS – short growing season perennial pasture

Composition of pastures in livestock grazing areas

Differences in the hydrologic characteristics of pastures (Chapter 4) meant that is was necessary to divide livestock grazing areas into different pasture types, as for rural residential land. Broadacre and dairy areas were divided into annual, short and long growing season pastures. The inclusion of long growing season pastures was based on the regional breakdown in Figure 3-5. Some long growing season pastures in dairy areas are irrigated. The area of irrigation is based on information provided by Southern Rural Water⁶. It was assumed that only dairy enterprises would support irrigated pasture and that most dairy pastures would have a perennial base. It was also assumed that there would be an increasing proportion of perennial pastures relative to annual pastures in broadacre areas, reflecting an intensification of the production system. The mix of pasture types is given in Table 3-5.

		Dairying		Broadacre grazing			
Year	LGS ² perennial	SGS ³ perennial	Annual pasture	LGS ² perennial	SGS ³ perennial	Annual pasture	
1990:							
LGS areas	80%	20%	0%	40%	50%	10%	
SGS areas	0%	80%	20%	0%	40%	60%	
2003							
LGS areas	85%	15%	0%	45%	50%	5%	
SGS areas	0%	85%	15%	0%	50%	50%	
2010							
LGS areas	90%	10%	0%	50%	50%	0%	
SGS areas	0%	90%	10%	0%	60%	40%	
2020							
LGS areas	95%	5%	0%	55%	45%	0%	
SGS areas	0%	95%	5%	0%	70%	30%	
2030							
LGS areas	100%	0%	0%	60%	40%	0%	
SGS areas	0%	100%	0%	0%	80%	20%	

• Table 3-5 Mix of pasture types in dairy and broadacre grazing areas¹.

1 % is percentage of area under dairy or broadacre grazing.

2 LGS – long growing season perennial pasture

3 SGS – short growing season perennial pasture

⁶ Data provided indicated the total area of land irrigated by surface water and groundwater. Irrigation area was first assigned to horticulture and any residual area to dairy. It was assumed that the area under irrigation would not increase.





 Figure 3-5 Assumed growing season length for WatLUC sub-catchments. Long growing season associated with milder and wetter summer climate in Otways and in western coastal areas.

3.6 Land use and land use change in WatLUC sub-catchments

Data presentation

The ten land use change scenarios were developed in individual spreadsheets that linked to the same basic data sets: AC data on agricultural land use, the 2003 land use data set and EVC coverage. The spreadsheets apply the land use change trends, perform the necessary area adjustments and partition grazing land into various pasture types, rural residential land into relevant vegetation covers and native vegetation into various hydrologic groupings. All calculations are carried out on a sub-catchment basis. Graphs (in the spreadsheets) show the breakdown, for each sub-catchment, into each of the major land uses for the periods 1990, 2003, 2010, 2020 and 2030. The spreadsheets also have pie charts showing the breakdown of land uses for the study area as a whole. Examples of outputs for the base scenario are given in Appendix D (especially D.3, D.4).⁷

⁷ With 10 different scenarios, there are too many charts to reproduce them all in this report.



A series of maps for the base case scenario have been produced which illustrate the key features of the land use change scenarios (Appendix D.5).

Land use change from 1990

Table 3-6 summarises the changes in the major land uses between 1990 and 2030 under each of the land use change scenarios. It consolidates the change in areas of pasture and grassland and of plantations, forests and woodlands. Areas are rounded to the nearest 100 ha. There are some small differences in areas between land use change scenarios that reflect area adjustments rather than real differences between scenarios.

A summary of the main features of each land use change scenario is given below:

- Base case over 11,000 km² of broadacre grazing land is displaced by other land uses between 1990 and 2030, particularly cropping (3,500 km²), dairying (3,800 km²), forestry plantations (1,800 km², of which 1,350 km² is blue gum plantation), nature conservation (1,470 km²) and rural residential land use (520 km²). Despite the significant increase in grasslands and grassy woodlands, the net area of pasture and grassland declines by over 5,000 km². The area of all forms of woody perennial vegetation increases by over 2,100 km² and the net area of perennial pasture and grassland increases by over 4,800 km².
- *Historical trend* the loss in broadacre grazing land is greater than under the base scenario, due to larger changes in cropping (4,000 km²) and dairying (6,300 km²). Under this scenario, the net area of pasture and grassland contracts by almost 6,000 km². The increase in area under grapes (6,000 ha) is greater than under the high grape scenario.
- High crop the area of crop expands by over 4,750 km². The rate of expansion in low rainfall farm forestry species was set at a lower rate in this scenario, due to competition for land with cropping. The net area of pasture and grassland declines by almost 6,500 km² and the area of perennial pasture and native grassland increases by 3,800 km², almost 1,000 km² less than the base case.
- *High dairy* dairy pastures expand by almost 7,000 km², resulting in an almost 14,500 km² contraction in broadacre grazing and a reduced expansion in cropping (3,500 km²). The area of perennial pasture and grassland increases by almost 5,400 km².
- *High forestry* the area of forestry plantation expands by over 2,400 km², due largely to an expansion in blue gum plantations (to 1,800 km²). Increases in cropping and dairying (3,400 km², 3,650 km², respectively) are below the base case, but the loss in broadacre grazing only marginally greater. The net area of pasture and grassland contracts by over 6,000 km² and the area of woody perennial vegetation increases by over 2,800 km².
- High revegetation the increase in land under nature conservation uses is extended to over 2,500 km² (for a total area of approximately 10,100 km²). However, since the target for



vegetation restoration (the endangered EVCs) is mostly grasslands or grassy woodlands, the increase in woody perennial vegetation $(2,200 \text{ km}^2)$ is only marginally greater than the base case. The decline in pasture and grassland area is approximately 5,200 km², although the area of perennial pasture and grassland increases by 5,100 km².

- *IUCN* this has the lowest level of vegetation restoration of any scenario. The increase is only 780 km², just over half that in the base case. This difference is largely accounted for by increased areas under cropping (3,640 km²) and dairying (4,000 km²).
- Rural residential expansion in rural residential uses increases to over 750 km². This is
 associated with an increase in woody perennial vegetation cover of 2,200 km².
- *High grapes* the predicted expansion in vineyard area is over 4,000 ha, more than double the base case.
- Broadacre grazing even with this scenario, over 9,000 km² is lost to this land use. The 2,500 km² increase in dairying occurred between 1990 and 2003. The predicted increase in crop area was less than 3,000 km². The decline in net pasture and grassland area is a little under 4,500 km², although the area of perennial pasture and grassland increases by almost 5,400 km². Rates of expansion in softwood plantations and low rainfall forestry were set at a lower levels for this scenario than in the base case. Expansion in woody perennial vegetation cover was almost 1,750 km², the lowest of any scenario.

3.7 Discussion

The approach to deriving land use change scenarios

There are several potential sources of error in deriving the land use change scenarios, particularly for agricultural land uses. Most of these relate to the use of AC data and have been described previously. The assumptions are considered reasonable, given the level of investment in deriving the scenarios. The approach has avoided the unwarranted assumption that land use is evenly distributed across SLAs by using the 2003 land use map (and not the AC data) as the baseline for the scenarios.

					Land use cha	ange scenarios				
Land use	Base	Historical	High Crop	High Dairy	High forestry	High Revegetation	IUCN	Rural Residential	High Grapes	Broadacre grazing
Cropping	350,300	398,300	476,500	350,200	343,500	329,900	363,800	344,200	349,500	296,700
Broadacre grazing	-1,132,300	-1,433,200	-1,165,300	-1,445,700	-1,175,700	-1,178,500	-1,093,100	-1,146,700	-1,133,300	-908,200
Dairying	382,900	632,000	307,600	696,300	365,300	359,500	398,700	379,700	382,700	251,700
Horticulture: vegetables	-1,500	-1,500	-1,500	-1,500	-1,500	-1,500	-1,500	-1,500	-1,500	-1,500
Horticulture: orchards	400	400	400	400	400	400	400	400	400	400
Horticulture: grapes	1,900	6,000	1,900	1,900	1,900	1,900	1,900	1,900	4,100	1,900
Native vegetation	146,800	146,500	146,800	146,800	145,800	254,600	78,200	146,600	146,600	146,800
Plantations: hardwoods	134,800	134,700	125,000	134,800	179,700	125,000	134,800	134,800	134,800	125,000
Plantations: low rainfall spp	16,200	16,300	8,100	16,300	24,400	8,100	16,200	16,300	16,300	5,400
Plantations: softwoods	23,300	23,200	23,300	23,300	38,800	23,300	23,300	23,300	23,200	4,500
Rural residential	51,700	51,700	51,700	51,700	51,700	51,700	51,700	75,500	51,700	51,700
Urban residential	12,500	12,500	12,500	12,500	12,600	12,500	12,500	12,500	12,500	12,500
Commercial	11,000	11,000	11,000	11,000	11,000	11,000	11,000	11,000	11,000	11,000
Transport	1,700	1,700	1,700	1,700	1,700	1,700	1,700	1,800	1,700	1,700
Pasture and grassland ¹	-540,000	-591,900	-648,400	-540,000	-600,900	-522,300	-540,000	-537,400	-541,300	-447,100
Plantations, forest & woodland ²	213,500	213,300	195,500	213,500	282,000	216,100	199,900	217,000	213,500	174,100
Perennial pasture & grassland ³	483,900	486,500	384,100	538,800	430,500	510,800	476,200	471,700	482,800	538,200

Table 3-6 Change in area (ha) of land use between 1990 and 2030 for all WatLUC land use change scenarios

1. Change in total area of pasture and grassland, including sown and unsown grazed pastures and native grasslands and grassy woodlands.

2. Change in total area of all forms of tall woody vegetation, including forestry plantations, revegetation areas on rural residential land and restored native forests, woodlands and shrublands.

3. Change in total area of perennial pasture and native grasslands and grassy woodlands.



Although considerable effort has been made to ensure the scenarios are well founded, their accuracy can only be tested over time. The value of the scenarios is that they place broad and generally realistic limits on the amount of change in particular land uses and on the rate of change. They represent the likely envelope of potential alternative land use "states" for the WatLUC study area and mean that the hydrological impact assessments can be realistic and that they should be credible. They will reflect the incremental nature of land use change and the mixed nature of land use. Hydrologic change estimates will not be based on unrealistic levels of land use change.

Land use change

The scenarios anticipate pronounced changes in land use across the Corangamite and Glenelg Hopkins CMA regions between 1990 and 2030. However, the most pronounced changes involve realignment of agricultural production and not change from agricultural to non-agricultural land use. With the exception of cropping, most scenarios predict that even these changes will be relatively modest beyond 2003.

The major land use change beyond 2003 is predicted to be the displacement of broadacre grazing by cropping. However, even in the high cropping scenario, this land use is only predicted to increase from about 3% of the WatLUC study area in 1990 to around 12% in 2030.

The major feature of land use change from a hydrological perspective is the "perennialisation" of the landscape (Figure 3-6). The scenarios predict a 600-700,000 ha increase in the net area of perennial vegetation across the study area between 1990 and 2030. This change is due to establishment of forestry plantations, native vegetation restoration and a predicted increase in the use of perennial species in pastures. Between 60 and 75% of this "perennialisation" is due to increased use of perennial species in pastures and the restoration of native grasslands and grassy woodlands under regional native vegetation plans (CCMA, 2003c; GHCMA, 2000). This will reduce the associated extent of hydrologic change, relative to that which would be experienced if the change was largely due to expansion in the area of woody perennial vegetation.

Changes in land use are most pronounced in the broadacre agricultural regions of the Glenelg, Hopkins and Portland coast drainage basins and is likely to have the greatest hydrologic impact in these areas. Maps reproduced in Appendix D.6 show how the net changes in perenniality of total vegetation cover accumulate along river basins. Changes in net perennial cover are most pronounced along the Mt Emu Creek (a tributary of the Hopkins River), Glenelg River and in some of the Portland coast catchments, with a 20-40% increase. The level of increase in woody cover is generally less (although sub-catchment 65, Stokes River is an exception to this), with an increase in woody perennial cover at the end of river systems of less than 10% for all but those in the Portland Coast basin.





 Figure 3-6 Change in total woody and non-woody perennial vegetation cover, by WatLUC sub-catchment between 1990 and 2030: base case scenario⁸

 $^{^8}$ Note +/- in legend indicates change in perennial cover of between -1% and +1%



4. Estimating Changes in Catchment Hydrology due to Land Use Change

4.1 Introduction

This section describes the numerical approach used in this study to predict the changes in catchment hydrology associated with land use change. There are five main steps involved (Figure 4-1) in the process for estimating hydrologic change. These five steps, the method of estimating irrigation volumes and the validation procedures used to assess the accuracy of the methods and their underlying assumptions are discussed below. A short description of the SoilFlux model is also provided.



Figure 4-1 Overview of method used to estimate hydrologic impacts of land use change scenarios



4.2 Alterations to modelling approach for WatLUC stage 1

The only significant change here from the approach developed in stage 1 of the study is in the use of the ForestImpact model (Munday *et al.*, 2001). The reasoning behind the change is fully described in section 4.10.

In stage 1, outputs of the SoilFlux model were tested and adjusted by comparison with the ForestImpact model. The ForestImpact model estimates the change in stream flow out of a catchment caused by: the area of land use change from pasture to forestry (this is the only land use change allowed in ForestImpact) and the change in forest age within the catchment. ForestImpact was developed from studies using statistical analysis of stream flow to estimate the effects of forest age and water use on stream flow.

In this stage, outputs from the SoilFlux model are compared to equivalent values from ForestImpact (as a check of modelling results), however SoilFlux outputs were not adjusted.

4.3 The SoilFlux model

Overview of SoilFlux

The SoilFlux model is a detailed model of the vertical movement of water and solute in the unsaturated zone of soil and surface geology and to and from a saturated zone (Daamen *et al.*, 2001a; Figure 4-2). SoilFlux uses Richard's equation for simulating water movement. Lateral flow to groundwater systems or streams is not modelled.



Figure 4-2 Processes simulated by the SoilFlux model

A 10 m deep profile of soil and geology is simulated here and vegetation root zones occur within this profile. A simple soil water balance for flows into and out of the simulated profile is given in Equation 4.1. Equation 4.1 ignores any change in storage within the profile over the simulation period as this is not considered to be significant over long time periods.

$$E = R + I - D - S \tag{4.1}$$

where E is the annual evapotranspiration, R the annual rainfall, I annual inputs from irrigation, D is annual net drainage from the base of the profile at 10 m (water movement below the root zone), and S is total annual surface run-off.

Whilst surface run-off, *S*, is simulated in the SoilFlux model the estimates provided are not likely to be accurate for a number of reasons including the following:

- lateral hill slope surface run-off processes are not represented in a one-dimensional model;
- daily rainfall totals are used, not storm sequences with varying rainfall intensity;
- no detailed information of the nature of the soil surface is available at the scale of the study area.

Therefore the *D* and *S* terms are lumped together as *L*, 'losses of water from the soil profile other than evaporation'. The SoilFlux model estimates a value of *L* for each of the 11 vegetation types in each of the sub-catchments. The effect of a land use change on the sub-catchment water balance is calculated as a change in *L*, i.e. a ΔL value or difference in *L* between vegetation types.

Uptake and evaporation of water by vegetation is influenced by the salinity of the soil solution. The accumulation of salt may ultimately limit evapotranspiration rates for vegetation that is direct takes up salty groundwater.

SoilFlux model inputs

The primary inputs to SoilFlux that are used to model the water balance of a sub-catchment include:

- rainfall and potential evaporation for a sub-catchment;
- vegetation type which is characterised in terms of monthly vegetative cover (e.g. leaf area index) and depth and distribution of the root system;
- soil and geology which are characterised in terms of the hydraulic properties of layers and the areal extent of a particular profile;
- groundwater depth and salinity associated with each profile type.

Climate inputs were prepared using daily rainfall records from Bureau of Meteorology gauges nearest to the sub-catchment, and spatial data sets from the Bureau of Meteorology for average



annual rainfall and potential evaporation. Soil, geology and groundwater depth and salinity data were taken from a state-wide groundwater pollution risk mapping project undertaken for the then Victorian Department of Natural Resources and Environment (Sinclair Knight Merz, 2001). The characterisation of vegetation types is summarised in section 4.4. The representation of soil profiles and depth to groundwater in a sub-catchment are presented in section 4.8.

4.4 WatLUC sub-catchments

WatLUC uses sub-catchments as the smallest unit of investigation. There are 66 sub-catchments (outlined in Figure 3-4 and numbered in Appendix D.2). Sub-catchment boundaries are taken from topographically defined surface water drainage boundaries and draw on recent work in the Sustainable Diversions Limit (SDL) project undertaken for the Victorian Department of Sustainability and Environment. In the Glenelg Hopkins region, the aggregation of SDL sub-catchments reflects the Catchment Management Authority's management unit breakdown.

4.5 Irrigation inputs

Hydrotechnology (1995) describe the PRIDE model that is used in this study to estimate the irrigation requirements of perennial pasture and grapes. PRIDE uses inputs of crop type and climate to predict a daily irrigation demand series. Crop factors relate pan evaporation to plant water requirements and vary both between crop types and over the year. Crop factors for this project were obtained from the PRIDE manual. The soil drainage factor used in PRIDE was set to one, reflecting free draining conditions.

PRIDE is usually used to determine irrigation demands in a region as opposed to individual farm requirements. The irrigation information required for the SoilFlux model must reflect the daily pattern of irrigation application to a small area of land. In the case of grapes, the daily pattern generated in PRIDE is used directly as an input to SoilFlux. The irrigation schedule for perennial pasture is calculated by triggering an irrigation event (infiltration of 80 mm) when the cumulative sum of the difference between evaporation and rainfall reaches a set level. The trigger level for each catchment was adjusted so that the irrigation delivered the average annual water requirements estimated in the PRIDE model. It was assumed that irrigation of perennial pasture occurs only between October and March and is allowed to vary between years.

The average irrigation requirements predicted by PRIDE were 3.1 ML/ha for perennial pasture and 1 ML/ha for irrigated grapes across the whole study area. These irrigation volumes are a little lower than those used in Stage 1 but are thought to be more representative of land management practice in the study area.



4.6 Step 1: Hydrologic characterisation of WatLUC land uses

Representation of land uses

The land uses included in the land use change scenarios are represented as one or more of the following vegetation types by SoilFlux:

- 1. Annual Pasture dryland
- 2. Perennial Pasture short growing season dryland
- 3. Perennial Pasture long growing season dryland
- Perennial Pasture long growing season irrigated land
- 5. Native grassland dryland

- 6. Annual Crop dryland
- 7. Forest Plantation dryland
- 8. Woodland dryland
- 9. Low Rainfall Farm Forestry dryland
- 10. Grapevines dryland
- 11. Grapevines irrigated land

Table 4-1 summarises the correspondence between land uses discussed in Chapter 3 and these 11 vegetation types modelled by SoilFlux. SoilFlux is not used to model urban and commercial land uses. For these land uses, L is estimated as a fraction of rainfall (Table 4-1).

Land Use	SoilFlux Vegetation type	Comments
Cropping	6	
Broadacre grazing	1, 2, 3	
Dairying	1, 2, 3, 4	
Horticulture: vegetables	4	Small area. Soil water balance estimated using irrigated perennial pasture (Veg Type 4).
Horticulture: orchards	11	Small area. Soil water balance estimated using irrigated grapevines (Veg Type 11)
Horticulture: grapes	10, 11	
Native vegetation	5, 7, 8	See table below
Plantations: hardwoods	7	
Plantations: low rainfall spp.	9	
Plantations: softwoods	7	
Rural residential	1, 2, 3, 8	
Urban residential	None	Water flux L estimated as 40 % of rainfall
Commercial	None	Water flux L estimated as 60 % of rainfall
Transport	1	Soil Water balance estimated by annual pasture (Veg Type 1)

Table 4-1 Correspondence between WatLUC land use and SoilFlux vegetation types.

Native vegetation was represented by several SoilFlux vegetation types, based on the EVC (Table 4-2). EVCs were grouped into six types, based on overstorey height and canopy cover.

Vegetation types and leaf area index

Leaf area index (LAI) is used as an input to the SoilFlux model to calculate the potential vegetation water use on a daily basis (i.e. the maximum possible vegetation water use). LAI is converted to a partitioning coefficient for evaporation that divides the total potential evaporation between vegetation and the soil surface (for a high leaf area in wet soil conditions more evaporation will occur from leaves than from the soil surface). Both vegetation water use and evaporation from the soil surface decrease from the potential (or maximum) values as the soil profile dries out.

Table 4-2 Representation of different classifications of native vegetation.

EVC grouping	Represented as SoilFlux vegetation type		
Forest	Forest Plantation		
Grassland	Native Grassland		
Grassy Woodland	Use both 'Native Grassland' and 'Woodland'		
Shrubland	Woodland		
Woodland	Woodland		
Wetland (total area in SW Victoria < 50 km ²)	Native Grassland		

Figure 4-3 and Figure 4-4 show the LAI time series that are used to represent the 11 vegetation types. Irrigated and rainfed grapevines are modelled with the same seasonal development of leaf area.



 Figure 4-3 Monthly leaf area indices for the pastures (PP – perennial pasture; SGS – short growing season; LGS – long growing season) and annual crop.





 Figure 4-4 Monthly leaf area indices for remaining SoilFlux vegetation types. (LRFF = low rainfall farm forestry).

Vegetation types and root distribution

The other input to the SoilFlux model that differentiates between vegetation types is the root distribution. The root distribution is parameterised by 4 inputs:

- the minimum or shallowest root depth, z_1 (m)
- the depth of the maximum root density, z_2 (m)
- the maximum root depth, z_3 (m)
- factor, ω, for exponential decline in root density with depth (m)

The relative root density increases linearly between z_1 and z_2 from 0.0 to 1.0. Equation 4.2 is used to calculate the root density between z_2 and z_3 .

Relative Root Density =
$$\exp\left(\frac{-(z-z_2)}{\omega}\right)$$
 for $z_2 \le z \le z_3$ (4.2)

The parameters used for each vegetation type are given in Table 4-3 and the root distributions shown in Figure 4-5.



Root depth inputs	Annual Pasture	Perennial Pasture – Dryland	Perennial Pasture – Irrigated	Annual Crop	Native Grassland	Forest Plantation & LRFF	Woodland	Grapevine
Minimum depth (m)	0.005	0.005	0.005	0.005	0.005	0.01	0.01	0.01
Depth of maximum root density (m)	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3
Max depth (m)	0.6	1.5	0.9	1.5	1.5	8.2	5.0	2.0
Root density factor ¹	0.1	0.2	0.15	0.15	0.3	0.8	0.5	0.5

Table 4-3 Parameters of the root distributions for SoilFlux vegetation types

1 Factor for exponential decline in root density. Depth (m) over which root density is reduced to 1/e (~ 1/3) of the upper value.



 Figure 4-5 Root distributions input to the SoilFlux model for different vegetation types. Note that the following pairs of vegetation types have the same root distribution: short and long growing season perennial pasture; irrigated and dry grapevines; and forest plantation and low rainfall farm forestry (deepest roots at 8.2 m).

4.7 Step 2: Run SoilFlux model

Spatial analysis is used to identify up to 12 different soil/geology profiles that occupy at least 1 % of the area of each sub-catchment. Four different depth to watertable conditions are modelled at the lower boundary of the profile, with one of those conditions allowing gravity drainage of water (i.e. a unit hydraulic gradient). The SoilFlux model is run for every combination of up to 12 profiles, four depth to watertable conditions and 11 vegetation types. The period modelled was from 1960 to 2000 inclusive. Average annual fluxes of evapotranspiration, drainage and surface run-off (E, D and S respectively, Equation 4.1) were calculated for the years from 1981 to 2000.



Equivalent runs were undertaken for each of the 66 sub-catchments with their own climate characteristics and profiles. There were potentially over 30,000 SoilFlux model runs completed as part of this study. In less than 1% of runs , numerical instability within the model did not allow completion. In these cases a simple gap filling procedure was applied to estimate the missing values using the large number of successful runs.

4.8 Step 3: Calculate sub-catchment *L* Values

The variable L is used to represent the 'average water loss from a soil profile other than losses to evaporation' and is calculated as the sum of surface run-off (*S*) and drainage below the root zone (*D*). In a sub-catchment, an average L value for each vegetation type is calculated by weighting the L values associated with each possible combination of (soil/geology profile) and (depth to watertable). The weighting is calculated as the proportion of the total sub-catchment area represented by each profile and depth to watertable combination. Two examples of the distribution of soil/geology profiles are given in Figure 4-6. Examples of the variation in average annual Lvalues are given in Figure 4-7 and Appendix E.

The implicit assumption in the calculation of L values in this way is that all vegetation types are equally likely to occur on any soil/geology profile.



 Figure 4-6 Percentage area of the 6 most commonly occurring soil/geology profiles in the Upper Moorabool sub-catchment (#1) and the Grange-Burn sub-catchment (#64).





Figure 4-7 Average annual loss (L) value associated with different vegetation types for the six most common soil profiles in the upper Moorabool sub-catchment (#1). Water table depth set at 2 m. Negative values indicate net groundwater discharge and positive values net groundwater recharge.

Figure 4-8 demonstrates the variability of annual L values with climate and vegetation type and shows that very large differences in L can result from a change in land use. Negative values occur when forest plantation types have a net uptake of groundwater from the watertable (which in this case is at 2 m depth). Average L values vary between about 260 mm/y for an irrigated pasture and about 25 mm/y for a forest plantation. In this sub-catchment, with an average rainfall of 780 mm, there is little difference in L from short growing season perennial pastures (e.g. phalaris) or either annual pastures or crops. Average L for a summer active native grassland is much lower (87 mm/y in this case).

4.9 Step 4: Apply land use change scenarios

The total effects of land use change scenarios (Chapter 3) are calculated as the sum of effects of all land use changes that occur. Each land use change (e.g. 'broadacre grazing' to 'forestry', or 'broadacre grazing' to 'cropping') causes a change in the sub-catchment water balance. The effect on the water balance is calculated using the area undergoing the change and the difference between the *L* values associated with the old and new land uses (i.e. a ΔL value associated with the change).





Figure 4-8 Annual L values in the Upper Moorabool sub-catchment (#1) for one soil type and an underlying depth to watertable of 2 m.

The sum of all land use changes in a sub-catchment gives a total ΔL value. ΔL values are calculated for each period of change, the periods considered are those between the following years: 1990, 2003, 2010, 2020, 2030 (section 3.5) and for cumulative effects (1990 to 2030). These ΔL values are calculated for each land use change scenario (section 3.5).

Appendix F provides examples of the influence of different land uses on total water yield in a subcatchment.

4.10 Step 5: Hydrogeological analysis

Overview

Once a total ΔL value is calculated for the sub-catchment the effects of the land use change are partitioned between a change in stream flow and the associated effect on shallow groundwater systems and a change in recharge of deep groundwater systems. In stage 1 of the study we presented the recharge areas for deep aquifer systems and an approach to estimating 'deep recharge'. The same recharge areas and approach have been used in the current stage of WatLUC and the approach is summarised again below.

The method estimates ΔL in each sub-catchment for each land use change scenario, as described above. The partitioning of ΔL and *L* between water flow beneath the root zone and surface run-off

is not attempted because the approach is not appropriate for estimating this partition, especially at the scale of a WatLUC sub-catchment. For the purposes of this study it is considered unnecessary to partition L in this way; a good hydraulic connection between the streams and the shallow groundwater system is assumed for the study area.

The remaining part of the water balance that does need to be described is the deep drainage of water to confined aquifer systems. It is assumed that water draining to deep aquifer systems is effectively lost from the streams/near-surface groundwater systems. We use an informed (but subjective) assessment for the partitioning of L between:

- streams/shallow groundwater systems, *L*_s and
- deep groundwater systems, *L*_d.

The relationship between *L*, L_s and L_d is given below, introducing parameters *a* and *b* (Equation 6-1).

$$L = L_s + L_d$$

$$L_s = aL$$

$$L_d = bL$$

$$b = 1 - a$$
(4-3)

Five categories or hydrogeological zones were defined (Table 4-4) and the values of *a* and *b*, (and hence L_s and L_d) are assumed to be homogeneous in these zones. The ranges of values for *a* and *b* reflect the method used and the scale at which it is applied.

Hydrogeological Zone	Range for <i>a</i>	a value used	Range for <i>b</i>	<i>b</i> value used
1	> 0.99	1.0	< 0.01	0
2	0.95 to 0.99	0.97	0.01 to 0.05	0.03
3	0.85 to 0.94	0.90	0.06 to 0.15	0.10
4	0.50 to 0.84	0.70	0.16 to 0.50	0.30
5	< 0.50	0.40	> 0.50	0.60

Table 4-4 Parameters associated with the hydrogeological zones.

The values in Table 4-4 are used in the following way. An area considered to be within Zone 1 has the total volume *L* remaining within the streams/near-surface groundwater system (shallow system), but if it is in Zone 4, for example, 70 % of *L* remains in the shallow system and 30 % leaks to deep groundwater systems. The partitioning between deep and shallow recharge is taken to be the same for ΔL as it is for *L* when considering the effect of a land use change.



In Victoria, Groundwater Management Areas (including Water Supply Protection Areas) are classified as unconfined or confined (for the purpose of this study these can be considered to be shallow and deep respectively). In parts of the project study area that are not classified as Groundwater Management Areas (GMAs) it can be assumed that groundwater resources are not easily exploited and that shallow groundwater systems are dominant with respect to the near-surface hydrology (Zone 1 above). GMAs for unconfined aquifer systems can also be assumed to be in Zone 1 with the recharge area of the GMA coincident with the GMA boundaries. The recharge area associated with a GMA of a confined aquifer system lies completely (or almost completely) within the GMA boundary (see below).

Hydrogeological zones are assigned using the GMA boundaries and the 1:250,000 surface geology maps. The zone boundaries are either GMA boundaries, boundaries of surface geology types or are hand-drawn boundaries that are an interpretation of geological features. The mapping was undertaken at a 1:250,000 scale that is considered to be appropriate for the size of the sub-catchments in this study. Therefore, a confined GMA area will be divided into 2 or more sub-areas, each with independent values of *a* and *b* (representing recharge areas and confined areas).

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 Rcharge Areas

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The results of the interpretation of hydrogeology are shown in Figure 4-9.

 Figure 4-9 Hydrogeological zones representing the partitioning of water available for recharge or run-off between: 1) shallow groundwater/streams and 2) deep confined groundwater systems.

4.11 Validation of WatLUC modelling procedures

Recent literature

Some recent scientific papers review the effects of land use change on components of catchment hydrology in Australia. These papers provide an opportunity to check on the results and methodology used in WatLUC. Although a direct correspondence is not expected with studies undertaken in other areas, the comparison can improve confidence in WatLUC results and highlight features of the WatLUC approach that differ from other studies.

Zhang *et al.* (2001) review the water use of forest and grassland using data collated from about 250 water balance studies across the world. Generalised functions are fitted to describe the water use (or evapotranspiration, ET) of forests and grassland as a function of average annual rainfall. These functions collate information from many different environments and are not expected to match the ET modelled in the WatLUC study exactly, although they provide a useful comparison. Figure 4-10 plots the Zhang functions and also the annual ET modelled by SoilFlux for 'annual pasture' and 'forest plantation' averaged for each WatLUC sub-catchment.



 Figure 4-10 Average annual evapotranspiration plotted against rainfall in all subcatchments for 'annual pasture' and 'forest plantation' modelled by SoilFlux. Generalised functions for ET of forest and grassland (Zhang *et al.*, 2001) are shown as lines.

The correspondence between the WatLUC outputs and the Zhang *et al.* (2001) functions (Figure 4-10) is as good as can be expected. Several features are worth noting:



- forest evapotranspiration is constrained to be at or below about 950 mm/year in the SoilFlux model because areal potential evaporation does not exceed this value in the WatLUC study area. Thus the Zhang functions show a greater ET for forests when rainfall is greater than 1200 mm.
- evapotranspiration of annual pasture modelled by SoilFlux is tending towards being equal to rainfall for rainfall ≤ 500 mm/year. A similar relationship is shown by the raw data collated by Zhang *et al.* (2001) for grassland but not by their fitted ET function (the function does not approach rainfall until rainfall < 400 mm/year).
- The features shown by the WatLUC data in relation to the Zhang functions also seem to be shown by equivalent data from Holmes and Sinclair (1986) for Victorian catchments⁹.

Another relevant study by Walker *et al.* (2002) summarises approaches to estimating the effects of land use change on deep drainage and groundwater recharge. The approach developed in the WatLUC project using the SoilFlux model is very similar to the application of the WAVES model discussed by Walker *et al.* (2002).

Petheram *et al.* (2002) summarised measurements of groundwater recharge made in 41 Australian studies. They concluded that recharge under trees was negligible in most environments with rainfall less than 1200 mm, this result is consistent with the WatLUC results, allowing for the constraint of a maximum potential evaporation of 950 mm. Petheram *et al.* (2002) fitted two log-log relationships between recharge and annual rainfall for annual vegetation, one for sandy soils and the other for non-sandy soils. The recharge values calculated in the WatLUC project for annual vegetation types (crop and pasture) generally fall between the two curves fitted by Petheram and certainly within the scatter of their data sets.

Comparison of streamflow

A project undertaken by Sinclair Knight Merz that investigated the Sustainable Diversion Limits (SDLs) of streams across Victoria provides an opportunity to cross-check WatLUC results at an appropriate scale. The SDL project used data from a large number of stream gauges across Victoria and, put simply, developed a relationship between catchment characteristics and average annual run-off volume. This relationship was then applied to estimate run-off volume in all SDL project catchments.

Average annual run-off volume is not estimated directly in WatLUC, but is equivalent to the difference between total *L* for a sub-catchment and the volume partitioned to deep aquifer recharge

⁹ These data were plotted by Zhang *et al.* (2001).

(section 4.10). Figure 4-11 compares stream flow estimated in the SDL project and annual run-off volume estimated from WatLUC modelling results. Agreement is considered to be reasonable, given that the two estimation methods are completely unrelated. Both projects use models to estimate stream flow, and therefore may produce poor estimates where assumptions are not met. However, it can be seen that in general the differences between sub-catchments are similar in both projects. This provides further support for the WatLUC modelling approach.



Figure 4-11 Comparison of stream flow estimated in the SDL project and WatLUC L values calculated for each sub-catchment using the 1990 distribution of land uses.

Streamflow volume estimated by WatLUC methods are greater than those estimated in the SDL project (Figure 4-11). Given this uncertainty, more emphasis should be placed on estimates of percentage change in streamflow that on estimates of either volumetric changes in flow or flow depth.

Comparison with the ForestImpact model

In stage 1 the ForestImpact model was used to check and adjust the results from the SoilFlux model. In the current stage of WatLUC, the adjustment of SoilFlux results is no longer undertaken for the reasons presented below.

ForestImpact is an empirically-based model developed from studies that analysed stream flow records in catchments with forests of changing age (see Appendix G). Average annual stream flow is characterised as a function of forest age for a range of forest types. Therefore a good correspondence between the results from the process-based SoilFlux model with the empirically-founded ForestImpact model will strengthen confidence in the WatLUC results.



The ForestImpact model has recently been updated and changes were made in the representation of Blue Gum and pine plantations. These changes are discussed in Appendix E. In practice, the changes do not greatly alter the results of the application of ForestImpact within the WatLUC study area.

Blue Gum plantations were modelled as a 13 year rotation that included one fallow year. The updated version of ForestImpact was used to estimate an average annual response of streamflow over a rotation period with respect to grassland (annual pasture). This was compared with outputs from SoilFlux averaged over a 20 year period (equivalent to 1981 to 2000) for all possible forest rotations (i.e. beginning in 13 different years) and also for annual pasture. A standard soil profile with gravity drainage as the lower boundary condition was used in SoilFlux (as in Stage 1).

Figure 4-12 shows the ratio (ΔL ForestImpact) / (ΔL SoilFlux) for a land use change from annual pasture to forest.



Figure 4-12 Ratio of model outputs ForestImpact/SoilFlux for the difference in stream flow between blue gum plantation and grassland plotted against catchment rainfall. Points shown as (♦) are within a range of catchment rainfall values where a good correspondence is expected, hollow symbols (◊) are points outside this range.

The difference in stream flow between a Blue Gum plantation and grassland is similar in the ForestImpact and SoilFlux models for catchment rainfall between about 600 mm/y and 950 mm/y (Figure 4-12). Below 600 mm/y, average rainfall, stream flow from a forested catchment is approximately zero for both models, however ForestImpact estimates about 100 mm/y streamflow

under grassland¹⁰. Therefore the ratio of the outputs between the two models increases as annual rainfall decreases below 600 mm/y and the SoilFlux ΔL value tends to zero.

In WatLUC stage 1, the SoilFlux ΔL values were adjusted using the ForestImpact ΔL values. This adjustment is now considered to be unnecessary and inaccurate for rainfall less than about 600 mm/y because: ΔL is very small and the use of the ForestImpact at these low rainfall values may be unreliable. It would also be expected that stream flow is very low in these sub-catchments and small changes in vegetation water use may be more significant.

Sub-catchments with rainfalls greater than 950 mm/y also have large ForestImpact/SoilFlux ratios (Figure 4-12). This occurs because maximum forest water use is constrained in the SoilFlux model by the areal potential evaporation of the sub-catchment (areal potential evaporation is described by Wang *et al.*, 2001). The areal potential evaporation is close to 950 mm/y across almost the entire study area. When catchment rainfall increases above 950 mm/y, forest water use does not increase in SoilFlux, but continues to do so in ForestImpact (see Figure 4-10). Hence the ratio of outputs from the two models also increases.

The constraint of forest water use by areal potential evaporation (Wang *et al.*, 2001) may or may not be realistic. The arguments for and against this constraint are listed below.

Support for the constraint of forest water use by areal potential evaporation:

- Wang *et al.* (2001) consider areal potential evaporation to be an accurate representation of maximum forest water use for extensive forest areas but indicate that this evaporation rate may be exceeded for small isolated forest plantations (tending toward point potential evaporation).
- It seems reasonable that climatic conditions other than rainfall constrain the maximum forest water use. Lower air temperatures, lower solar radiation loads and higher humidities are expected in south-west Victoria relative to the rest of the Australian mainland.

Arguments against the constraint of forest water use by areal potential evaporation:

 Zhang *et al.* (1999) estimate a 'maximum forest water use' of about 1400 mm/year using data from many different forests worldwide. The forest water use estimated in ForestImpact follows Zhang *et al.* and therefore is not constrained by potential evaporation.

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¹⁰ The stream flow response functions used in the ForestImpact model are adjusted for subcatchment rainfall using the Zhang *et al.* (2001) functions for forest and grassland ET. The Zhang function for Grassland ET shown in Figure 4-10 does not asymptote to rainfall unless rainfall \leq 300 mm/year.



Kuczera (1985) and Watson *et al.* (1999) indicate that a maximum forest water use of between 1200 and 1400 mm/y occurs in the Melbourne water supply catchments where the areal potential evaporation is about 950 mm/y. The point potential evaporation in the Melbourne water supply catchments is about 1150 mm/y and is also exceeded by the water use estimates of Kuczera (1985) and Watson *et al.* (1999).

It is possible that areal potential evaporation may not be a good constraint of forest transpiration for WatLUC. In future it may be found that another estimate of potential evaporation would be better suited. An adjustment of SoilFlux ΔL values using a factor ranging from 1.0 to 2.5 was initially evaluated. However, the comparison with stream flow estimated in the SDL project (Figure 4-11) suggests that the catchment water balance is reasonably well represented by the SoilFlux results at higher rainfalls and therefore no adjustment of *L* or ΔL was made in the 8 sub-catchments with rainfall higher that 950 mm.

As stated previously, the ForestImpact/SoilFlux ratio (equivalent to the ratios shown in Figure 4-12) was used in stage 1 of WatLUC to adjust the SoilFlux ΔL values (for all possible land use changes). Coincidentally, all the pilot catchments in stage 1 had annual rainfall within the 600-950 mm range and the adjustment factors were scattered around a value of 1. The reasonably close correspondence of the stage 2 results from SoilFlux and ForestImpact for rainfalls within this range indicates the models show a similar response to land use change and that the adjustment factor would again lie close to one.

In addition, the differences in the adjustment ratio are found to be indicative of differences in the distribution of rainfall within a year for the sub-catchments with rainfall between 600 mm/y and 950 mm/y. Therefore, use of the adjustment ratio would remove the differences between sub-catchments that are considered to be real and should be preserved.

ForestImpact model only uses average annual rainfall and therefore does not differentiate between sub-catchments with the same annual rainfall, but different seasonal distributions. Therefore, for a given annual rainfall total, differences in the adjustment ratio are the result of differences in the SoilFlux ΔL values. For example, sub-catchment 10 has an annual rainfall of 693 mm/year and an adjustment ratio of 1.06 whereas in sub-catchment 57 annual rainfall is almost identical at 704 mm/year, but the ratio is 0.74. Figure 4-13 shows the average monthly distribution of rainfall in these two sub-catchments. As expected, the more even distribution of rain throughout the year in sub-catchment 10 results in a smaller SoilFlux ΔL value and a larger adjustment ratio.

To reiterate, the SoilFlux model results have not been adjusted using ForestImpact in the current stage of WatLUC. The comparison of the results from the ForestImpact model and the SoilFlux model is best considered to be a 'sanity check' that compares two different approaches rather than an opportunity to adjust the SoilFlux ΔL values. A useful outcome of the comparison is the

highlighting of the constraint of potential evaporation on the water balance estimated by the SoilFlux model.



Figure 4-13 Average monthly rainfall in sub-catchments 10 and 57.

Review of hydrogeological characterisation

A workshop was held in October 2003 at the Glenelg Hopkins CMA in Hamilton to discuss the assumptions of the WatLUC modelling approach prior to commencement of stage 2. One of the issues was the extent of groundwater flow between sub-catchments. A possible approach was presented for calculating a water balance in South Australian sub-catchments where groundwater flow between sub-catchments was significant.

Dr. Peter Dahlhaus (a workshop participant) was engaged by Sinclair Knight Merz to assist with the assessment of the significance of groundwater flow in some sub-catchments. A brief summary of the points made in his discussion paper¹¹ is given below.

• The groundwater and topographic divides do not overlie each other in all sub-catchments. In particular, there are some deep lead systems that carry groundwater flow from one sub-catchment to a second sub-catchment that is not 'downstream' in terms of surface water drainage. Groundwater flow in deep leads occurs in the following cases (see Appendix D for map listing sub-catchment numbers):

¹¹ The paper is included as Appendix H.



- from sub-catchment 18 to 40
- from sub-catchment 10 to 40 (and perhaps also out of study area)
- from sub-catchments 10, 4 and 5 to 2
- Regional groundwater flow may also occur across topographic divides:
 - regional groundwater flow from 19, 20 and 8 to 7
 - possibly other areas near Willaura and Hamilton.
- Groundwater Flow to Lakes may be significant, especially around Lake Corangamite
- Diversion of surface water flows from surface water storages across catchment boundaries will be important to sub-catchment water balance and the effects of land use change on the water balance.

In discussion with Peter Dahlhaus it was proposed that a net groundwater flow that resulted in a change in sub-catchment water balance of less than 1 mm/y would not be considered significant to this part of the study. In some areas these groundwater flows may be highly significant to catchment hydrology, but in the context of this regional study of land use change, the results of the sub-catchment water balance calculations would not be greatly affected by groundwater flow.

Following on from the discussion with Peter Dahlhaus, Darren Bennetts (Latrobe University, Bundoora) was also contacted regarding groundwater flow around Willaura (sub-catchment 35). The estimated maximum groundwater flow of 80-160 ML/year along a 30 km transect (i.e. a similar length to a sub-catchment side boundary) supports the conclusion that groundwater flows are not highly significant.

Effects of land use change between 1990 and 2003

Sub-catchment 65 (Stokes River sub-catchment), in the far west of the study area, experienced a large increase in plantation area between 1990 and 2003, a trend that was projected to continue by the land use change scenarios. This sub-catchment is gauged and provides the opportunity to both determine whether changes in streamflow as the result of land use change can be detected and check measured streamflow with WatLUC estimates.

A generalised additive model (GAM) analysis was used to remove the effects of climatic variability and identify the underlying trend in stream flow. Figure 4-14 shows the trend in stream flow for sub-catchment #65 is downwards, which broadly supports the conclusion that the Blue Gum plantations in the sub-catchment are already reducing surface water yields. The graph shows the downwards trend 'commencing' in the late 1980s, well before Blue Gum plantation establishment. However, this is largely an artefact of the GAM analysis, which operates as a form of running



average. The timing of the point of inflexion in the graph (the commencement of the downwards trend) provides only a coarse guide to the timing of streamflow change.



• Figure 4-14 Normalised trend in stream flow in three sub-catchments with contrasting levels of afforestation between 1990 and 2003.

Figure 4-15 shows the change in stream flow between 1990 and 2003 estimated using the GAM analysis of stream flow records and that estimated by WatLUC. The effects of afforestation appear to be over-estimated by WatLUC, particularly for sub-catchment #65. One explanation for this is that WatLUC assumes that all plantations established by 2003 are mature in a hydrologic sense (i.e. water use is representative of a fully developed plantation), whereas this takes several years.

Comparison with estimates of recharge to deep aquifer systems

In Victoria, areas with significant groundwater resources have been recognised as Groundwater Management Areas (GMAs). A Permissible Annual Volume (PAV) of groundwater extraction has been estimated within these GMAs to assist in the management of groundwater resources. In brief, the PAV is intended to be a volume of groundwater that can be extracted without: depleting the resource in terms of either quality or quantity; or affecting (groundwater dependent) environmental systems.





• Figure 4-15 Reduction in stream flow between 1990 and 2003 estimated by GAM analysis of stream flow records and estimated using the WatLUC approach.

It is difficult to estimate a PAV accurately and several different methods have been used in Victoria to produce estimates that differ by orders of magnitude. Comprehensive and relevant data sets are often not available. However, with this qualification, the PAV can provide a useful check on the estimates of deep groundwater recharge made in the WatLUC study. The Paarate GMA and the Portland GMA are deep and confined aquifer systems that lie within the WatLUC study area. They have PAV volumes of 4,600 ML/year and 21,000 ML/year respectively (Sinclair Knight Merz, 1998a;1998b) and the PAV can be considered to represent an annual average recharge volume.

The WatLUC study estimates the change in deep groundwater recharge caused by land use change using the partitioning approach described in section 4.10. Using this approach the estimates of deep recharge in the WatLUC study are 6,500 ML/y and 26,000 ML/y for the Paarate and Portland GMAs respectively. This relatively good agreement supports the WatLUC method used to calculate deep recharge.

4.12 Changes in flow-related stresses in streams

Flow Stress Ranking (FSR) is a tool developed aiming to provide an objective ranking of flow stress in all river systems across Victoria (Sinclair Knight Merz, 2004b). The ranking establishes a relative indication of threat to river health based on the level of water extractions by rural, urban, and industrial users. The underlying assumption is that a measure of the ecological health of a river can be characterised by the differences in flow regime between natural and modified conditions.

Five hydrological indices were developed, based on departure from the natural range, providing a robust means of characterising hydrologic stress. The analysis is based on monthly flow data, which has been found to provide a similar indication of hydrologic stress as daily data. The five indices are:

- the coefficient of variation (CV);
- the variation of the two lowest monthly flows in each water year (Q90);
- the variation of the highest monthly flow in each water year (Q10);
- the proportion of time that monthly flows are near zero (PDZ); and,
- the timing of the highest and lowest monthly flows in each calendar year (SP).

These five indices are combined into a single FSR index from 0 to 1, where 0 represents extremely stressed conditions and 1 represents pristine condition. Indices are calculated on an annual basis and for winter and summer flows.

FSR indices were calculated for each of the WatLUC sub-catchments for current and all 2030 land use change scenarios. A comparison of the current and the 2030 indices provides an indication of the likely impact that changes in land use will have on flow related dimensions of river health.

FSR requires monthly streamflow inputs. *SoilFlux* was run on a monthly time step and the outputs were multiplied by the area of each land use to produce monthly streamflow series for each subcatchment and for each land use change scenario¹². The flow series represent the total upstream flow and so reflect the cumulative upstream impact of land use change on streamflow.

The majority of the WatLUC catchments correspond directly with catchments used in the FSR project¹³. In these cases, monthly current and natural flow series derived as part of the FSR project were adopted. The 2030 land use change scenario flow series were calculated by factoring the current FSR flow series by the ratio of the 1990 and 2030 WatLUC total water yield for that sub-catchment. Current and natural flow series were derived for the 16 of the 21 remaining WatLUC sub-catchments that did not have corresponding FSR sites using the method specified in Table 4-5. Flow series could not be derived for the other five sub-catchments as they do not have defined stream courses or are terminal lake catchments.

¹² Taking account of partitioning between surface water flows and deep aquifer recharge (section 4.10)

¹³ Sinclair Knight Merz (unpublished data) – Flow stress ranking project for the Department of Sustainability and Environment, Victoria.



Sub-catchment	Mean annual flow (ML/yr)	Method
6	305,394	REALM output, also accounting for private diverters and farm dams
10	68,543	REALM output, also accounting for private diverters and farm dams
11	10,363	Not possible to accurately derive flow.
13	249,535	Not possible to accurately derive flow.
14	27,723	Not possible to accurately derive flow.
15	22,221	Not possible to accurately derive flow.
17	30,913	Transpose FSR site 23401 & account for private diverters & farm dams
19	73,193	Transpose FSR site 23405 & account for private diverters & farm dams
20	66,118	Not possible to accurately derive flow.
29	12,275	Transpose FSR site 23526 & account for private diverters & farm dams
33	12,405	Gauge 235216 & account for private diverters & farm dams
37	21,395	Transpose FSR site 23607 & account for private diverters & farm dams
38	39,219	Transpose gauge 236204 & account for private diverters & farm dams
41	105,164	Transpose gauge 236203 & account for private diverters & farm dams
45	513,110	Gauge 236209 & account for private diverters & farm dams
49	72,218	Transpose 237205 & account for private diverters & farm dams
52	57,861	Transpose FSR site 23710 & account for private diverters & farm dams
53	18,846	Transpose gauge 237207 & account for private diverters & farm dams
54	114,312	REALM output, also accounting for private diverters and farm dams
55	174,767	REALM output, also accounting for private diverters and farm dams
56	231,186	REALM output, also accounting for private diverters and farm dams

Table 4-5 Method used to derive flow series for sub-catchments for which data was not available under the FSR project (Sinclair Knight Merz, unpublished data).

A sensitivity analysis undertaken as part of the FSR project showed that a minimum of 15 years data is required to accurately derive FSR indices. There were five catchments (59-61, 63) for which there were only 9.5 years of data available due to a discrepancy between the start date of the WatLUC study and the period of gauged data.

Figure 4-16 plots values for the various sub-indices and for the overall annual, summer and winter indices for two contrasting sub-catchments. Higher index values for sub-catchment 36 indicates a more natural flow regime. For both sub-catchments, the summer flows are more altered than winter flows. Two flow elements (Q90 – low flows; PDZ – low flow periods) are very highly altered in the upper Moorabool sub-catchment: which is consistent with a river with several substantial water storages.





 Figure 4-16 Flow stress indices and index values for sub-catchments 1 (upper Moorabool) and 36 (Muston Ck). ai – annual index, si – summer index, wi – winter index, other abbreviations as above.


5. Changes in Water Yield with Land Use Change

The modelling approach used by WatLUC allows the hydrologic change associated with land use change to be expressed in terms of total water yield, surface water yield and recharge to deeper confined aquifer systems. Results can be expressed on a sub-catchment and whole of drainage basin basis, and can show the incremental, cumulative effect of hydrologic change along a river system.

Results can be expressed in percentage terms or as volumetric changes. The use of percentages is more robust. However, volumetric terms have been used to indicate the scale of change in flow that might be expected.

Thirty-two different representations of land use have been assessed using the WatLUC modelling approach¹⁴ in each of the 66 sub-catchments. With so much data generated and so many combinations, it will only be possible in this report to present and discuss a small, representative selection of the outputs. This chapter provides some examples of the model output and summary graphs and statistics. Further information is provided in Appendix I (for surface water) and Appendix J (for deep aquifer recharge).

5.1 Change in sub-catchment water yield

An example of the change in gross sub-catchment water yield¹⁵ with time (for sub-catchment #1) is shown in Figure 5-1, with other examples provided in Appendix I.1. All of the land use change scenarios follow the same path between 1990 and 2003, as they are based on the same combination of land uses. Beyond 2003, the streamflow responses will diverge if the various land use change scenarios predict differing hydrological responses. With the examples included (Figure 5-1, Appendix I.1), the changes in streamflow by 2030 ranged between \pm 100% of the 1990 value.

Increased flow in the relatively dry sub-catchment #3 (near Geelong; Appendix I.1) was associated with increased urban and commercial land use. The greatly reduced flow in sub-catchment #65 (Stokes River; Appendix I.1) was mostly associated with hardwood plantation development. The land use change scenario resulting in the greatest reduction or increase in yield varies between sub-catchments (see also Appendix E).

¹⁴ 1990 and 2003 scenarios are identical for all land use change scenarios. Thus there are five base case scenarios and three scenarios for forestry, dairy, cropping, broadacre grazing, historical, grape, native vegetation, IUCN and rural residential.

¹⁵ This is includes changes in surface water flows and recharge to deep aquifer systems.





Figure 5-1 Predicted change in streamflow in WatLUC sub-catchments in response to land use change scenarios. Sub-catchment 1 (mean annual flow = 108 mm)

The divergence in the flow response to land use change between the various scenarios is generally much less than the scale of change in flow between 1990 and 2030. The range in changed flows for the various 2030 scenarios is typically 20% or less of the magnitude of change between 1990 and 2030. While space constraints do not permit results from all of the land use change scenarios to be presented in this report, those results generally closely reflect those for the base case.

Maps showing how total water yield changes in all WatLUC sub-catchments are given in Appendix I.2. While information for other scenarios is available, only the maps for the base case scenario are presented. Changes relate to potential flows leaving the sub-catchment and do not account for within sub-catchment storages or diversions.

The extent and timing of changes in potential yield for the base case are quite variable between sub-catchments. Yield reductions by 2030 in two sub-catchments (#62 and #65) exceed 50% and exceed 25% in a further six sub-catchments. Forestry is a major driver of yield loss in many of the sub-catchments with the largest (percentage) losses in flow. Establishment of new native vegetation contributes to yield losses in these sub-catchments and many of those with intermediate range yield reductions.

Increased potential water yields were recorded in six sub-catchments; located near Geelong, on the Bellarine peninsula and along the Otway coast. Changes are associated with increased rural residential, urban and commercial land use.

5.2 Surface water flows

Change in surface water flow at a sub-catchment level is the residual of total water yield after recharge to deep, confined aquifers has been allocated (section 4.10). Appendix I provides a series of maps for the base case scenario that show:

- change in volumetric flow at the sub-catchment level (Appendix I.3);
- change in volumetric flow as it accumulates along river systems, expressed as a percentage of mean annual flow (MAF) and a flow volume (Appendix I.4 and I.5);
- changes in surface water flow as a percentage of the sustainable diversion limit (SDL; Appendix I.6).

The maps represent the loss in flow generation capacity rather than what would be the change in flow at the outlet of the sub-catchment. The values plotted do not take account of diversions, storages within the sub-catchments or inter-basin transfers. They are all expressed in terms of change in mean annual flow.

Change in sub-catchment volumetric flow

Changes in volumetric flow are greatest for sub-catchments in Glenelg, Portland coast and Hopkins basins. Only 10 of 22 sub-catchments are predicted to experience flow reductions less than 10 GL/y, with two predicted to experience flow reductions exceeding 50 GL/y. The largest predicted losses in surface water flow are from sub-catchments with high current and predicted levels of forestry development and relatively high rainfall.

Several sub-catchments near Geelong and on the Otway Coast are predicted to have flows increase by up to 10 GL/y by 2030 (Appendix I.3).

Figure 5-2 shows the predicted change in potential surface water flows in 2030 (expressed as a depth of water) for each of the drainage basins and the WatLUC study area as a whole. The Glenelg and Portland coast drainage basins, particularly, are predicted to experience large reductions in surface water flows. The Moorabool basin, as a whole, is predicted to experience little net change in flow, with losses in flow in the sub-catchments along the stem of the river (#1 and 2) losing flow and sub-catchment #3 gaining flow through urbanisation. The predicted average loss of surface water flow across the entire WatLUC study area is approximately 15 mm/y.

With the exception of the Glenelg and Portland coast drainage basins, differences in the change in flow between land use change scenarios are small. The IUCN scenario, which has the smallest area

of restored native vegetation, is predicted to have the least reduction in surface water flow. The greatest reductions in streamflow are predicted for either the high forestry or high native vegetation scenarios. Only in the Glenelg basin is the difference between the scenario with the greatest and least reduction in surface water flow greater than 5 mm/y.



Figure 5-2 Changes in estimated total surface water yield with land use change scenarios and river basins.¹⁶

Table 5-1 expresses the predicted change in surface water flow for the eight main drainage basins in volumetric and percentage terms. Losses in potential flow in the Hopkins and Glenelg basins exceed 100 GL/y for all scenarios. Total potential losses across the entire WatLUC study area range between about 590 and 750 GL/y. The Glenelg River basin, the largest in the study area, accounts for around 50% of those losses.

In percentage terms, the greatest flow losses are expected to occur in the catchments of the Portland Coast basin (21-25%). The only other basins in which flow losses exceed 5% are the Glenelg, Hopkins and Lake Corangamite basins. The average flow loss due to land use change across the entire WatLUC study area ranges between 7.1 and 8.9% of mean annual flow under 1990 land use.

¹⁶ WatLUC in the legend to Figure 5-2 indicates the entire WatLUC region.



Scenario	Moorabool R.	Barwon R.	L.Coranga- mite	Otway Coast	Hopkins R.	Portland Coast	Glenelg R.	WatLUC study area
Base	0 (0.1%)	-12 (-1.5%)	-44 (-8.5%)	-21 (-2.0%)	-151 (-7.2%)	-87 (-22%)	-332 (-10%)	-647 (-7.7%)
Crop	1 (0.4%	-9 (-1.1%)	-41 (-7.9%)	-20 (-1.9%)	-142 (-6.8%)	-83 (-21%)	-315 (-9.6%)	-609 (-7.3%)
Forestry	-1 (-0.3%)	-14 (-1.7%)	-47 (-9.1%)	-26 (-2.5%)	-159 (-7.6%)	-99 (-25%)	-402 (-12%)	-747 (-8.9%)
Grape	0 (0.0%)	-13 (-1.5%)	-44 (-8.5%)	-21 (-2.0%)	-152 (-7.2%)	-87 (-22%)	-332 (-10%)	-649 (-7.7%)
Dairy	0 (0.0%)	-14 (-1.6%)	-46 (-9.0%)	-22 (-2.0%)	-160 (-7.6%)	-93 (-24%)	-335 (-10%)	-670 (-8.0%)
Historical	0 (0.1%)	-13 (-1.5%)	-45 (-8.8%)	-21 (-2.0%)	-159 (-7.6%)	-92 (-24%)	-334 (-10%)	-664 (-7.9%)
IUCN	1 (0.6%)	-10 (-1.2%)	-41 (-8.0%)	-20 (-1.9%)	-135 (-6.4%)	-80 (-21%)	-309 (-9.4%)	-594 (-7.1%)
Native Vegetation	-1 (-0.3%)	-17 (-2.0%)	-49 (-9.5%)	-22 (-2.1%)	-174 (-8.3%)	-94 (-24%)	-349 (-11%)	-705 (-8.4%)
Rural Residential	1 (0.4%)	-12 (-1.4%)	-44 (-8.5%)	-21 (-2.0%)	-151 (-7.2%)	-87 (-22%)	-332 (-10%)	-645 (-7.7%)
Broadacre Graze	1 (0.5%)	-10 (-1.2%)	-40 (-7.8%)	-17 (-1.6%)	-145 (-6.9%)	-82 (-21%)	-301 (-9.2%)	-594 (-7.1%)

Table 5-1 Change in mean annual streamflow (GL/y, %1990 flow) in drainage basins with 2030 land use change scenario

Cumulative changes in flow along river basins

Appendices I.4 and I.5 have maps which show the accumulation of flow changes along river basins, both in % MAF and volumetric terms. They show the average and total change, respectively, in surface flow above the outlet of the particular sub-catchment. These estimates are indicative only, as they do not take account of the effect of storages or diversions. Despite this they are useful in highlighting the potential for flow stress to accumulate along a river basin.

The maps indicating percentage change in flow (Appendix I.4) show that the effect of flow reductions are 'diluted' in relative terms along the larger river basins. They also show that flow stress is expected to increase over time.

Volumetric flow maps (Appendix I.5) highlight both the potential additive effects of land use change and the very large reductions in potential flow that could be expected in the middle and lower reaches of the Glenelg River and in the lower reaches of the Hopkins River.

Changes in flow compared with the sustainable diversions limit

Appendix I.6 shows the predicted change in surface flow as a percentage of the SDL. The two numbers are not strictly comparable, as the former is an annual flow and the latter relates only to flows between July and October¹⁷. The SDL comparison has been included because it provides a

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¹⁷ While there are flows outside this period in many river systems, it is the main period of natural flow and should account for 50-75% of MAF. Changes in surface flow estimated by WatLUC procedures have been divided by 2 to allow a more valid comparison with SDL.



useful insight into flow-related stress in a river system. By 2030, the modelling predicts that potential mean annual flow reductions due to land use change will exceed the SDL by a factor of between 5 and 25 times across the majority of the Lake Corangamite, Hopkins and Glenelg drainage basins and parts of the Barwon basin.

Appendix I.7 brings together the potential WatLUC flow changes and the existing uses of surface water across the study area. The sum of the two is expressed relative to the SDL¹², but in Appendix I.7 is not cumulative along a river basin.

These two sets of maps indicate that the despite the larger flow reductions in the Glenelg River basin, the greatest level of flow related stress with use and land use change would be experienced in the upper Hopkins, Lake Corangamite and parts of the Barwon basins. This is confirmed by the maps in Appendix I.8, which show how the data mapped in Appendix I.7 accumulate down a river system.

Changes in flow stress ranking indices

Annual, summer and winter flow stress indices have been calculated for 61 or the 66 subcatchments and for each of the 2030 land use change scenarios (Figure 5-3, Appendix I.9). Averaged across the WatLUC study area, winter flows are generally much more natural (i.e. have higher flow stress index values) than summer flows. All of the 2030 land use change scenarios would result in a reduction in the flow stress index value for each of the three indices. The reduction would range between about 0.06-0.08. There would be little difference in FSR between scenarios (Figure 5-3).

Flow stress, particularly during summer, is already endemic across much of the WatLUC study area (Appendix A). The Moorabool and Hopkins drainage basins are the worst and most consistently affected by alterations to the natural flow regime. Land use changes predicted by the various scenarios would exacerbate flow stress (Appendix I.9). Predicted changes in summer indices are typically greater than those in winter indices. The most extreme changes in FSR with land use change are expected to occur in sub-catchments of the Glenelg and Portland Coast drainage basins. However, the areas with the greatest (annual) flow stress under the 2030 land use change scenarios were those with some of the least natural current flow regimes, the upper and lower Moorabool sub-catchments (#1 and 2) and the Fiery Creek sub-catchment (Hopkins basin; #39).





 Figure 5-3 Land use change scenarios and flow stress ranking winter, summer and annual indices.

5.3 Groundwater

Water was only allocated to deep groundwater systems in a small number of sub-catchments (see Figure 4-9). Changes in volumetric recharge to groundwater are given in Appendix J. The major deep aquifer recharge areas in the west of the region are located in areas with extensive forestry development and in which the land use change scenarios predict a high level of future development. Up to 8.4 GL/y losses in recharge are expected by 2030 in the sub-catchment (#66) with the greatest predicted reduction in deep aquifer recharge.



6. Discussion

6.1 Land use change in south-west Victoria

The rapid pace of land use change experienced in south-west Victoria during the late 1990s appears to have abated in all but the cropping and rural residential sectors. The hardwood plantations industry believe that they will achieve their target plantation area for the region within the next few years and are likely only to expand incrementally beyond that level. Adjustment in the dairy industry following deregulation may curtail expansion in that sector, although lack of irrigation water in the Goulburn and Murray valleys may make the south-west region's dairy industry more attractive to new entrants. Cool season wines are entering a period of oversupply in domestic and international markets and it may be a decade before there is significant opportunity for expansion. At best, broadacre grazing is unlikely to even hold its own in the face of competition from cropping.

While the cropping industry are not certain that the current rates of growth will be maintained, they still expect rapid growth relative to other agricultural sectors. Expansion of residential and urban land uses into areas currently used for agriculture is likely to continue. However, such changes are likely to be confined to a relatively small part of the study area– around Ballarat and Geelong, along the Bellarine Peninsula and in coastal areas to the east of Cape Otway.

The WatLUC study area's two Catchment Management Authorities have their own ambitious plans for land use change. Even if they were delayed by 20 years (to 2050) in achieving their minimum targets for native vegetation restoration – increasing all endangered EVCs to 15% of their pre-European coverage – the rate of vegetation restoration would be over 5000 ha/y.

From a hydrologic perspective, the key feature of all land use change scenarios is the predicted increase in perennial vegetation cover. This is associated with intensification of grazing in areas where it remains, native vegetation restoration, new forestry development and implementation of regional salinity management plans.

WatLUC modelling found that there would be little difference in the hydrologic change associated with the ten land use change scenarios, at least at a drainage basin level. The main drivers of hydrologic change – expansion in cropping, perennial pasture establishment, native vegetation restoration, forestry development and urbanisation - are incorporated in broadly similar ways for all of the scenarios. Accuracy of WatLUC modelling is therefore most sensitive to how well the underlying assumptions in the base case scenario represent the progression of land use change in the region.



The two assumptions of greatest concern are the rates of transfer between annual and perennial pasture¹⁸ and the rate of restoration of native vegetation. Expansion of cropping may help to provide financial resources for both activities and see the setting aside of less productive land for nature conservation. However, farmers with large cropping operations may reduce the intensity of the grazing operations to devote their attention to cropping and not convert pastures at the rate anticipated. The value of land that is suited to cropping may mean that some EVCs, particularly grasslands and grassy woodlands, are not restored to the level targeted by the CMAs.

In both cases, there would be a reduced level of increase in perennial cover in the catchments and the predicted impact of land use change on surface water and groundwater recharge would be reduced.

The assumption has been made that the area of land under irrigation within the region will not increase. If the Wimmera-Mallee pipeline proceeds, some water that is currently diverted from Rocklands reservoir in the upper Glenelg catchment to the Wimmera system may be made available for irrigation in the Glenelg basin. Given the method of calculating change in water yield and the relatively high L for irrigated agriculture, this would result in smaller reductions in water yield than are currently predicted here. However, unless there was a very large expansion in irrigation area this would not be significant at a drainage basin scale.

6.2 Methods for predicting hydrologic change associated with land use change The method for calculating sub-catchment water balance was developed and pilot tested in Stage 1 of the WatLUC project. In Stage 2 the scenario inputs have been updated and minor changes made to the method, including:

- the sub-catchment water balance results from the SoilFlux model are compared to ForestImpact model results but no longer adjusted by them, and;
- irrigation water use has been estimated using the PRIDE model (typically 3 ML/ha/year for irrigated perennial pasture and 1 ML/ha/year for irrigated grapevines) rather than through canvassing local and expert opinions.

These changes are seen as advances on the method applied in Stage 1. Firstly, the ForestImpact model does not consider the intra-annual distribution of rainfall that SoilFlux results indicate is significant. Also the constraints on evaporation are different for the two models and this interferes

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¹⁸ The transfer is to perennial pasture for broadacre grazing and dairy areas and from perennial pasture in rural residential areas.



with the model comparison in the 10 % of sub-catchments with highest rainfalls and the 10% of sub-catchments with lowest rainfalls.

The second change was made because it is considered that irrigation water use was over-estimated in Stage 1. This is supported by the results of the application of the PRIDE model that estimates irrigation requirements from evaporative demand.

Evapotranspiration in annual pasture and forest plantation vegetation types is broadly consistent with the global data set analysed by Zhang *et al.* (2001) (Figure 4-10). This comparison and others indicate that the sub-catchment water balance estimates are in line with estimates from other studies. Therefore it is unlikely that the results would change substantially if a different approach to estimating sub-catchment water balance was adopted, furthermore the conclusions of the study are even less likely to change.

The hydrogeological characterisation of the study area has been reviewed further by local experts and found to be adequate at the scale of WatLUC sub-catchments.

In summary, the method has been refined and the sub-catchment results found to be consistent with other studies and local expert opinion. The objective of WatLUC Stage 2 was to assess the effects of land use change at a regional scale in a way that was consistent across the study area. Stage 2 highlights sub-catchments whose surface water flows or deep aquifer recharge are likely to be most greatly changed. Within these sub-catchments, more detailed investigations will improve the understanding of the effects of land use change on catchment hydrology and natural resources.

WatLUC Stage 2 did not aim to and cannot resolve the effects of land use change on hydrology for small parts of sub-catchments.

6.3 Hydrologic response to land use change

One of the objectives of WatLUC is to, *'identify the scale of land use change required for particular adverse or beneficial effects'*. While it is not yet possible to quantify specific adverse or beneficial effects of hydrologic change, it is possible to explore hydrologic responses to land use change.

Regression analysis (Appendix K) for the base case scenario identified that four main land use changes explain almost 95% of the change in predicted total sub-catchment water yield (TSWY; expressed in mm/y). The equation (6-1) included four land use changes, that for the proportion of the sub-catchment under plantations, forests and woodlands (pfw), perennial pasture or grassland (pp) and urban land (urb) and commercial (com) land uses.

 $TSWY = -3.9956 - 201.18 \text{ pfw} - 28.071 \text{ pp} + 256.87 \text{ urb} + 349.04 \text{ com } r^2 = 0.9466$ (6-1)



Equation 6-1 indicates that for each 10 percentage point increase in land use, total surface water yield would change by:

- -20.1 mm/y for a change in plantations, forests and woodlands;
- -2.8 mm/y for a change in perennial pasture or grassland;
- +25.7 mm/y for urban land uses;
- +34.9 mm/y for commercial land uses.

The relatively small proportional change in urban and commercial land use¹⁹ meant that the change in area of woody vegetation (plantations, forest or woodland) was the most influential land use change at sub-catchment and drainage basin scale. Figure 6-1 shows how predicted total sub-catchment water yield changes with the proportion of a sub-catchment under woody vegetation and perennial pasture or grassland (with urban and commercial land use change set at their average values, 0.5 and 0.4%, respectively).

Under the base case land use change scenario, the average change in woody vegetation and perennial pastures and grasslands were 4.4% and 9.2%, respectively. The largest increases in area were 36.0 and 37.4%, respectively, which are much less than the full range indicated in Figure 6-1.

Average annual rainfall was found not to have a statistically significant influence on the change in total sub-catchment water yield.

6.4 Interpreting the results of WatLUC modelling

The assumptions and context of the WatLUC modelling results must be considered when they are interpreted. The predicted changes in flow only represent a change in *potential* water yield within a sub-catchment or drainage basin. Farm dams, water storages and irrigation or stock diversions mean that changes in L (the amount of unevaporated water) will not necessarily be expressed as changes in stream flow. For this reason, hydrologic changes expressed in depth or volumetric terms will almost always overstate the change in surface water flow or yield. Estimates of percentage change in water yield or surface water flow with time or between land use change scenarios are likely to be more accurate, but may still overstate the change at the outlet of the sub-catchment or drainage basin.

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¹⁹ Average of <1 percentage point across the WatLUC study area and no more than 7 percentage points in any individual sub-catchment.





Change in tree cover (% of sub-catchment)

Figure 6-1 Predicted change in total sub-catchment surface water yield (mm) with change in woody vegetation and perennial pasture and grassland.

Changes in *L* have been accumulated along river basins to indicate both where flow-related stresses originate in a river basin and how they either accumulate or are dissipated down basin. The presence of water storages, diversions and inter-basin or inter-sub-catchment transfers of water (in channels or as groundwater flow) are not accounted for; which means that accumulated effects are indicative only.

Comparison of predicted changes in flow due to land use change with the SDL have been introduced to provide further indication of flow-related stresses in a river system. It must be noted that WatLUC modelling provides estimates of mean annual flow, while SDL is a winter flow diversion limit. The two numbers are not strictly comparable and for this reason, whenever change in flow, current annual flow use and SDL are compared, the former are both divided by two to bring the numbers to a more common time frame. Again it is the relativity in numbers between subcatchments and along river systems that is most important and not the absolute value of the flow change:SDL ratio.

Estimates of post-1990 change in water yield, streamflow and deep aquifer recharge are reported for current (2003) land use and the land use mix under each change scenario at 2010, 2020, 2030.



The L values used in these estimates are those for a fully developed vegetation cover. For agricultural species (crops and perennial pastures) this can be assumed to be achieved in the year of establishment. However, for plantations and new stands of native vegetation, there will be a delay of at least several years between the vegetation being established and it fully expressing its impact on L.

The effect of this assumption on sub-catchment L and water yield estimates is reduced by the use of 10 year reporting intervals. This effectively allows much of the vegetation "established" in the intervening period to fully express its hydrologic impact. While it is acknowledged that this is a shortcoming with the modelling method, the simplification is consistent with reporting on a "mean annual flow" basis. To do otherwise would have greatly increased the modelling effort required.

Surface water flow estimates do not take account of delays until the effect of a change in recharge to shallow aquifers (part of the *L* term) is expressed as a change in streamflow. However, since groundwater flow is at least partly driven by hydraulics and the transfer of pressure²⁰, the delays may be no more than a few years even in parts of the WatLUC study area dominated by regional scale flow systems (e.g. the basalt plains). The use of 10 year reporting intervals also helps to reduce significance of this delay.

6.5 Water resource availability and flow-related stresses in south-west Victoria

WatLUC predicts that there will be a significant reduction in water resource availability in southwest Victoria. The loss in total surface water resources across the region, once the impacts of the 2030 land use change scenarios are fully realised, could amount to between about 600 and 750 GL/y (Table 5-1). Losses in recharge to deep aquifer systems, which are extensively developed for water resources, were estimated to be between about 17 and 21 GL/y. While large in volumetric terms, changes in potential surface water yield correspond to less than 10% of annual potential water yield for the WatLUC study area as a whole.

While land use change might be expected to reduce inflows into the WatLUC study area's major water storages in the headwaters of the Glenelg, Barwon and Moorabool Rivers, the extent of change is likely to be limited. None of the land use change scenarios anticipated high concentrations of woody or non-woody perennial vegetation establishment in these areas (Figure 3-6) and so further reductions in yield are limited (Appendix I.3).

²⁰ Groundwater discharge is driven by both groundwater flow from a recharge to a discharge area and the hydraulic transfer of water pressure. The addition of recharge to a more elevated water table quickly results in rising levels in connected water tables at low points in the landscape as the result of transferred pressure levels.



Reduced water resource availability is most likely to be experienced in the lower reaches of river systems and at locations where much of the unevaporated water recharges deeper aquifer systems (Appendix I.5, Appendix J). This is the result of the dispersed nature of land use change, the location of the major concentrations of woody and non-woody perennial vegetation establishment and the cumulative nature of the hydrologic changes with land use change.

In contrast to this, WatLUC modelling results, data on existing water use and the comparison with the SDL (Appendix I.8) suggests that upper and mid catchment areas in the Glenelg, Hopkins and Lake Corangamite basins are likely to experience the greatest level of flow-related stress in volumetric terms. This reflects strongly on the level of flow-related stress due to existing storages and diversions, as well as the potential effects of land use change.

Land use change is expected to further alter flow regimes in the WatLUC study area. Major reductions in winter and summer flow indices (> 0.2 units) are predicted in sub-catchments of the Portland Coast, Hopkins and Glenelg drainage basins (Appendix I.9). However, despite this, the sub-catchments that already have the most highly altered flow regimes (upper and lower Moorabool sub-catchments, #1-2) will continue to have the least natural flow regimes (annual and winter indices).

Regression analysis was used to determine the strength of correlation between land use change and both flow stress indices and changes in value of the indices. The best fits (Eq. 6-2 - 6-4) were between the change in flow stress and the percentage point change in both plantation, forest and woodland cover (pfw) and commercial land uses (com). However, change in land use does not have the same predictive power for change in FSR as it does for change in surface water flows (Eq 6-1).

$\Delta ai = -0.0394 - 0.4994 \text{ pfw} + 1.420 \text{ com}$	$r^2 = 0.34$	(6-2)
$\Delta wi = -0.05461 - 0.6925 \text{ pfw} + 3.384 \text{ com}$	$r^2 = 0.38$	(6-3)
$\Delta si = -0.03367 - 1.121 \text{ pfw} + 1.894 \text{ com}$	$r^2 = 0.47$	(6-4)

where,

 Δai , Δwi and Δsi are the change in annual, winter and summer flow stress index values, respectively.

Each 10% increase in sub-catchment woody vegetation coverage would reduce flow stress index values by between 0.050 and 0.112, depending on the index. Flow stress indices would increased by between 0.014 and 0.034 for each 1% increase in commercial land use within in a sub-catchment.



6.6 Implications for dryland salinity

WatLUC modelling suggests that land use changes that are likely to occur as the result of industry and population trends and implementation of regional native vegetation plans will significantly reduce recharge to the shallow water table aquifers that drive most salinity processes. Taken in a whole of region context, this suggests that land use change should help to combat dryland salinity issues in the Glenelg-Hopkins and Corangamite regions.

Very large reductions in water table aquifer recharge (or *L*) are expected in some sub-catchments (Appendix I.1 and I.2). However these often do not coincide with the region's main salinity hotspots. The change in recharge with the predicted land use changes is typically less than 25% and often less than 15% in salinity hotpot areas. While this is likely to slow the rate of expansion in salinity, it may not be sufficient to reduce its incidence.

Further work is required to evaluate the potential implications of WatLUC for dryland salinity within the study area.

6.7 Hot spots of land use and hydrologic change

Stage 2 of WatLUC has highlighted several areas where the base case and other scenarios anticipate a concentration of land use change that, if realised, would have significant hydrologic implications. These areas warrant further attention, to refine the land use change scenarios and estimates of likely hydrologic change and to assess the local and broader scale implications of such changes.

Several broad criteria could be used to identify 'hot spots' of hydrologic change, including changes in the perenniality of landscapes, potential water yield and the level of flow related stress. Appendix L outlines two approaches to the identification of such hot spots; the first included both land use and hydrologic change criteria and the second included only hydrologic change criteria. The results (Figure 6-2) are generally similar, but not identical.

Sub-catchments 49, 58, 65 and 66 in the Glenelg and Portland Coast drainage basins are highlighted as the highest priority hot spot areas using both approaches. Sub-catchment 51 in the Portland Coast basin and sub-catchment 62 in the Glenelg basin are included in the highest priority class if only hydrologic criteria are included. This group of six sub-catchments are the areas where any further work on hydrologic change should be concentrated.

The second rank sub-catchments include 38, 57, 63 and 64. These are located in the Hopkins, Portland Coast and Glenelg drainage basins. Otway Coast, Barwon and Moorabool basin subcatchments have a relatively low priority. This reflects the more limited extent of land use change, particularly to woody and non-woody perennial vegetation. The upper and lower Moorabool sub-



catchments already face high levels of flow-related stress and should be considered in any assessment of the impacts of changed flow regime.

a) Land use and hydrologic change criteria b) Hydrologic change criteria only Water and Land Use Change: hydrologic hot spots Water and Land Use Change: hydrologic hot spots Ν N Rank Rank Rank Rank 1 - 5 6 - 10 6 - 10 11 - 20 11 - 20 21 - 30 21 - 30 31 - 40 31 - 40 >40 60 Kilometers >40 60 Kilometers

• Figure 6-2 Hydrologic hot spots in WatLUC study area. Priority increases from blue to red, with dark red sub-catchments having the highest priority.

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7. Conclusions

The major objectives of WatLUC were to develop a suite of realistic land use change scenarios for the region and to understand the impacts of these scenarios on water movement through landscapes and on the availability and quality of water for consumptive and environmental uses. Although it has not addressed water quality, the second phase of the study has delivered on most of these objectives for the Corangamite and Glenelg Hopkins CMA regions. The approach has been applied consistently at the regional scale and has identified sub-catchments whose water regimes are likely to be greatly changed.

Realistic land use change scenarios have been developed on the basis of industry consultation, government endorsed natural resource management policy documents and observed population and land use trends. They predict that the pace of land use change observed in the late 1990s is unlikely to be maintained. However it is likely that there will be continued expansion in Blue Gum plantations in the west of the region over the next few years and on-going growth in the area of land under cropping, native vegetation and rural residential land uses over coming decades. The most remarkable features of land use change over the 40 years from 1990 that are predicted by the scenarios are the expansion in cropping at the expense of broadacre grazing and the increase in both woody and non-woody perennial vegetation cover.

While the various land use change scenarios anticipate quite different land use outcomes, this is not reflected in changes in water yield, surface water flow or recharge to deep aquifers at the drainage basin level. However, there are sometimes quite pronounced differences between scenarios at the sub-catchment scale. WatLUC modelling also predicts quite pronounced changes in catchment hydrology with time, as the scenarios develop. For drainage basins, these changes with time are much greater than are differences between scenarios. Most of the hydrologic change that is predicted by WatLUC modelling then is incorporated in the base case scenario.

WatLUC predicts that there will be a significant reduction in the availability of surface water and groundwater resources in south-west Victoria as the result of land use changes that occurred during the last decade and that may take place over the next 30 years. The loss in the total surface water resource could amount to over 600 GL/y on a mean annual flow basis and the loss in groundwater could amount to over 15 GL/y of annual average recharge to deep aquifer systems. These losses represent between 6 and 9% of total surface water flows generated within the study area and less than 1% of groundwater recharge, respectively. Around 50% of the surface water losses and over 90% of the loss in groundwater recharge would occur in the Glenelg drainage basin.

It is not expected that land use change will have a particularly marked effect on inflows to the study area's major water storages. Land use change, particularly the increase in woody and non-woody perennial vegetation, is likely to be less pronounced in the upper catchments of the Glenelg,



Barwon and Moorabool Rivers than in many other places in the region. Given the location and dispersed nature of land use change, the main impact on surface water resource availability is likely to be experienced in the lower reaches of the Glenelg and Hopkins river systems. Groundwater resources in deep aquifers in the far west of the region are also likely to be diminished.

WatLUC suggests that upper and mid catchment areas in the Glenelg, Hopkins and Lake Corangamite basins are likely to experience high levels of flow-related stress, expressed in terms of change in volumetric flow relative to the SDL. This reflects both existing uses of water in these areas and the potential effects of land use change.

The flow regimes of the Moorabool and Hopkins Rivers, the Mt Emu Creek and some tributaries of the Glenelg River are already quite altered. This is particularly true for summer flows. Land use change is expected to incrementally alter the flow regime of rivers and streams throughout the WatLUC study area. The 2030 land use change scenarios are likely to result in most of the region experiencing having summer and annual flow regimes that are quite different to the natural regime (flow stress index <0.75). The Moorabool River will remain the most stressed of the study area's streams.

An empirical relationship was developed to predict the potential hydrologic impacts of land use change. The relationship indicated that for every 10 percentage point increase in woody vegetation and perennial pasture or grassland cover within a sub-catchment, total potential water yield would fall by 20 and 2.8 mm/y, respectively. For each 1% increase in urban and commercial land uses, potential water yield would increase by about 2.6 and 3.5 mm/y, respectively. A similar relationship was derived for predicting flow stress indices, but has much poorer predictive capacity. A 10 % change in woody vegetation cover and a 1% change in commercial land use would alter the annual flow stress index by –0.050 and 0.014, respectively.

The impact of land use change scenarios on the incidence of dryland salinity in the WatLUC study area has not been fully investigated. However, the estimated reductions in recharge in many of the regions' dryland salinity hot spots should help to slow the development of dryland salinity.

WatLUC has identified several 'hot spot' areas for hydrologic change. These are areas where there is predicted to be a concentrated increase in the extent of woody and/or non-woody perennial vegetation cover; significant reductions in potential surface water flow generation, deep aquifer recharge and flow from upstream and/or substantial current or potential over-commitment of water resources. Hot spot areas include sub-catchments 49 and 51 in the Portland Coast basin and sub-catchments 58, 59, 62, 65 and 66 in the mid and lower reaches of the Glenelg River drainage basin. Further work to improve land use change predictions and to assess the extent and implications of hydrologic change, are required in these areas.



The upper and lower Moorabool River sub-catchments (#1 and 2) are already experiencing very highly altered flow regimes and should be included in any investigations that consider such impacts.

Recommendations for additional work to build on the data and analysis provided by this stage of WatLUC include the following:

- consider the implications of regional climate change projections on both land use change scenarios and catchment hydrology;
- evaluate the water quality implications of land use and hydrologic change;
- evaluate the implications of land use change for land and water salinity in regional priority areas.

It is recommended that the results of this stage of the study be communicated to government, industry stakeholders and the community throughout the region. Key natural resource management agencies should begin to consider the policy implications of this study.

The modelling approach used here has application in other landscapes facing land use, climate and hydrologic change.



8. Acknowledgments

The Water and Land Use Change study was overseen by a Steering Committee that comprised representatives of key private and public sector stakeholder organisations. Their input to the study was invaluable. They worked to secure funding and helped to ensure that the study remained relevant to the needs and issues of South-West Victoria. The work of the Steering Committee built on the foundation laid by a previous group of stakeholder representatives, who commissioned an initial scoping study and secured funding for Stage 1.

Members of the Steering Committee included:

- Associate Professor John Sherwood (Steering Committee Chair) Deakin University
- Dr Richard Benyon CSIRO Forestry and Forest Products
- Peter Codd Corangamite Catchment Management Authority (Stage 2)
- Peter Dixon Department of Primary Industries, Victoria
- Jon Drohan, then Dr John Kellas Green Triangle Regional Plantation Committee (Stage 2)
- Colin Dunkley Glenelg Hopkins Catchment Management Authority (Stage 1)
- David Fisken Central Victorian Farm Plantations Committee
- Terry Flynn Southern Rural Water
- Kath Gosden Corangamite Shire (Stage 1)
- Colin Hacking Southern Farming Systems
- Hugo Hopton South-East Water Catchment Management Board (Stage 1)
- Diana Lloyd Green Triangle Regional Plantation Committee (Stage 1)
- Sally-Anne Mason Corangamite Catchment Management Authority (Stage 1)
- Duncan McGillivery Deakin University, Cool Climate Wine Science Program
- Fred Stadter Department of Land, Water and Biodiversity Conservation, South Australia (Stage 1)
- Andrea van der Wouw WestVic Dairy (Stage 1)
- Martin van der Wouw WestVic Dairy (Stage 2)

The study was managed by the Glenelg Hopkins Catchment Management Authority on behalf of project partners. Jonathon Wearne and later Kylie Waller were project managers on behalf of the Steering Committee. Their contribution to the study was also greatly appreciated.

Prof. Tom Hatton of CSIRO Land and Water acted as an independent reviewer on behalf of the Steering Committee and provided helpful and constructive advice to the study team, particularly through stage 1 of WatLUC.



The project has been supported by the following organisations: Central Victorian Farm Plantations Committee; Corangamite Catchment Management Authority; Corangamite Shire; CSIRO Forestry and Forest Products; Deakin University; Department of Land, Water and Biodiversity Conservation, South Australia; Department of Primary Industries, Victoria; Department of Sustainability and Environment, Victoria; Glenelg Hopkins Catchment Management Authority; Golden Plains Shire; Green Triangle Regional Plantation Committee; National Action Plan for Salinity and Water Quality; Private Forestry Council of Victoria; South East Catchment Water Management Board; Southern Farming Systems; Southern Grampians Shire; Southern Rural Water Authority; Water for Growth; and WestVic Dairy.

Some base data for flow stress index calculations were derived from work undertaken by Sinclair Knight Merz for the Victorian Department of Sustainability and Environment.



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10. Glossary

Agricultural Census	A census of all primary producers reporting a gross value of production exceeding \$5000 p.a. The census collects information on land use, stock numbers and the amount and value of commodity production.
Backcast	Forecasting in reverse. Projecting land use change trends backwards in time. Used to determine the 1990 land use change scenario.
Correlation coefficient	A term used in regression analysis to indicate the degree of correlation between two variables. A correlation coefficient (r^2) of 100% indicate that all data fit on the line that marks the relationship between the two variables.
Cumulative flow	The accumulation of surface water flow along a river or drainage basin. In this report cumulative flow is reported on a sub-catchment basis and is the sum of all "flows" in the total catchment area above the sub-catchment outlet.
Deep aquifer recharge	Used in this report to denote those components of <i>L</i> that are considered to recharge deep and confined aquifer systems that do not discharge into streams. Figure 4-9 shows the hydrogeological zones in which deep aquifer recharge is considered to occur in the WatLUC study area.
Drainage basins	Major catchments or drainage systems. When used in this report, it refers to the Moorabool, Barwon, Lake Corangamite, Otway Coast, Hopkins, Portland Coast and Glenelg basins (depicted in Figure 2-4).
Evapotranspiration	Total evaporation from land surfaces, including from vegetation (transpiration and direct evaporation of water intercepted by plant canopies) and soil evaporation.
EVC	Ecological vegetation class. An EVC comprises one or a small number of vegetation communities with similar structural, floristic and ecological features and located in similar landscape positions.
GFS	Groundwater flow system. Ares of the landscape with similar geological and geomorphic characteristics and landscape processes that give rise to the incidence of dryland salinity.
LAI	Lead area index. The ratio surface area of vegetation cover to ground area.
Land management	Specific practices which apply for a particularly land use. For example, stubble retention and tactical grazing are management practices for cropping and grazing of modified pastures land uses, respectively.
Land use	The main use of land in terms of the commodity produced or service provided. Land use is classified according to the Australian Land Use Mapping framework (Bureau of Rural Sciences, 2002).
Land use change scenario	A mix of land uses at a particular point in time. Land use change scenarios were developed for WatLUC to reflect changes with time and different industry and policy drivers for land use change.
Loss L	Unevaporated water. The sum of recharge and surface run-off. WatLUC assumes that all <i>L</i> ends up reporting as either stream flow or deep aquifer recharge.
ΔL	Change in loss as the result of land use change
Modelling	The prediction of an outcome using one or a series of mathematical formulae.
Non-woody perennial vegetation	Includes all non-woody perennial plants, which in the context of WatLUC generally relates to sown perennial pastures and native grasslands.
Peri-urban	Pertains to the area of land adjacent to built up or urban areas.
Recharge	Water that infiltrates beyond plant roots to the water table.
Regression analysis	In this report refers to the derivation of the (linear) mathematical relationship between two variables. Regression analysis was used to derive a mathematical relationship that could be used to predict future land use and stock numbers from agricultural census data.



River basin	The entire catchment of a river. For some basins, the river and drainage basins may coincide (e.g. Glenelg River) and for others (e.g. Portland and Otway Coasts) there may be multiple river basins in a drainage basin.
Root density	The length of roots for a given volume of soil.
Saturated zone	That part of the soil or weathered rock profile below the water table, where (water) saturated conditions apply.
SDL	Sustainable diversion limit. The maximum volume of water that can be diverted from a sub-catchment during winter (July-October) while protecting the environment.
SLA	Statistical local area. The basic reporting unit for statistics published by the Australian Bureau of Statistics.
Stream flow	Water that flows along the course of streams and rivers.
Surface run-off	Water that moves across the land surface (as opposed to stream flow)
TSWY	Total surface water yield (in mm)
Unsaturated zone	That part of the soil profile above the water table.
WatLUC	The Water and Land Use Change study
Woody perennial vegetation	Vegetation dominated by woody perennials. In WatLUC, this could include forestry plantations, native vegetation (including forest, woodland, shrubland EVC groups), grape vines and orchards.



Appendix A Water resources of the WatLUC study area

This appendix provides an overview of the water resources of the WatLUC study area and their current levels of utilisation. Seven maps are provided, showing:

- Mean annual flow for each of the WatLUC sub-catchments
- Cumulative mean annual flow along river basins
- Sustainable diversion limit (SDL) for each of the WatLUC sub-catchments
- Current total surface water usage as a percentage of the SDL;
- Flow stress ranking: winter, summer and annual indices

The maps are based on SDL and flow stress ranking (FSR) data sets (Sinclair Knight Merz, unpublished data).

It should be noted that the SDL is the winter (July-October) diversion limit. Usage and flow are all annual measures.

Sub-catchment mean annual flow

Cumulative mean annual flow along river basins

N



Sustainable diversions limits



• Current use as % of SDL (by sub-catchment)



Current annual use has been divided by two to allow comparison with SDL, which relates only to the period July-October. Usage exceeding 100% indicates that water resources are overcommitted.

Flow stress ranking: winter index





Water and Land Use Change: Flow stress ranking - winter index

Water and Land Use Change: Flow stress ranking - summer index

Flow stress indices are numbers that indicate the relative naturalness of stream flows. A value of 1 indicates a fully natural flow regime: the index value declines as the degree of modification to flow regime increases.



• Flow stress ranking: annual index



Water and Land Use Change: Flow stress ranking - annual index

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Appendix B Land use trends in Agricultural Census data

Ararat



Agricultural land use area (ha)	Rate of change in land use (ha/y)	R ²
Total area of holdings	736	15.7%
Area of cropping	3,433	80.5%
Area of dairy pastures	61	0.1%
Area of broadacre grazing (sheep and beef cattle)	-2,768	50.1%

There is a strong trend of cropping displacing grazing in broadacre enterprises. There has been a consistent increase in the total area of holdings reported. The area of dairy pasture is close to static.



Colac Otway South



Agricultural land use area (ha)	Rate of change in land use (ha/y)	R ²
Total area of holdings	-676	22.8%
Area of cropping	37	16.3%
Area of dairy pastures	-708	21.9%
Area of broadacre grazing (sheep and beef cattle)	-5	0.0%

The total area of holding reported is declining, with most of this loss from dairy pastures. The areas of cropping and broadacre grazing are small. The latter is close to static and the former is increasing, but from a very small base.



Gleneig North



Agricultural land use area (ha)	Rate of change in land use (ha/y)	R ²
Total area of holdings	1,431	9.3%
Area of cropping	10	13.5%
Area of dairy pastures	696	61.9%
Area of broadacre grazing (sheep and beef cattle)	726	3.6%

The area of holdings is increasing consistently, although there appear to be some artefacts in the statistics in 1996 and possibly 1997. The area of dairy pasture is growing strongly, but from a low base. The area of broadacre grazing is also increasing, but the change is small in relation to the total area. Cropping is almost non-existent.



Glenelg South



Agricultural land use area (ha)	Rate of change in land use (ha/y)	R ²
Total area of holdings	872	15.0%
Area of cropping	21	1.3%
Area of dairy pastures	3,209	71.5%
Area of broadacre grazing (sheep and beef cattle)	-2,357	39.0%

The total area of holdings reported is increasing, with some possible statistical anomalies in 1995. There is a consistent trend for dairying to replace broadacre grazing. Cropping is a very minor land use.


Golden Plains North



Agricultural land use area (ha)	Rate of change in land use (ha/y)	R ²
Total area of holdings	-260	0.0%
Area of cropping	277	63.8%
Area of dairy pastures	-40	0.9%
Area of broadacre grazing (sheep and beef cattle)	-494	3.4%

The total area of holdings reported and the area of broadacre grazing are declining, although neither trends are strong. There is a strong trend for the area of cropping to increase from a small base. Dairy pastures are a minor land use and appear to be declining in significance.



Appendix C Industry Demand Projections for Cool Climate Wines

The general base rate of growth in vineyards was determined from industry demand and supply forecasts for cool climate wines (McGrath-Kerr Business Consultants, 2003). The gap in projected supply and demand for each grape variety was plotted (below) and a linear trend value was calculated. The trend value for each grape variety was weighted by the proportion of total demand to provide an overall estimate of the rate of change in demand. The rate of expansion in area of vineyards was set to match the average annual change in demand (approximately 3% p.a).



 Demand and supply predictions for cool climate grape production (data from McGrath-Kerr Business Consultants, 2003; analysis from Sinclair Knight Merz, 2004a)



Appendix D Examples of Land Use Change Scenario Outputs

D.1 Overview

This appendix provides examples that show the mix of land uses on a sub-catchment basis for the base scenario. A key to the land use codes is given below. All codes commence with the year the scenario relates to, which in the case below is 2003.

Only the base case scenario is reproduced here. While there are differences between the various scenarios, most differences are less pronounced than the progression over time with the base case. With the scaling used in the map-based presentation of land use change scenarios, there is generally little difference between scenarios for a particular land use. Outputs for a range of land uses under the remaining nine scenarios are also available.

Code	Land Use	Code	Land Use	
2003agc	agriculture: crop	2003fog	forestry: sugar gum or other low rainfa farm forestry species	
2003agg_b	agriculture: broadacre	2003fos	forestry: softwood (pine)	
2003agg_d	agriculture: dairy	2003rur	rural residential land	
2003hov	horticulture: vegetables - represented in model as irrigated long growing season pasture	2003urb	urban residential land uses	
2003hot	horticulture: trees - represented in model as grape vines	2003com	commercial land uses	
2003hog	horticulture: grape vines	2003tra	Transport	
2003nvg	native vegetation - does not include new native vegetation on rural residential land (2010-2030)	Mining	mining – considered to be a fixed land use	
2003foh	forestry: hardwood (blue gum plantation)	Water	water bodies – also considered to be fixed	



D.2 WatLUC sub-catchments

The following map acts as reference for the WatLUC sub-catchment numbers.





D.3	Mix of all land uses in WatLUC sub-catchments
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2003



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Base scenario: 2030



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D.4 Change in land use mix between 1990 and 2030







D.5 Land use distribution in 2030 under base case scenario

The following maps show the distribution of land use under the base case scenario in 2030. Sub-catchments are shaded according to the percentage under various land uses. Scales vary between land uses.



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Ν

60 Kilometers



Hardwood plantations









Rural residential







D.6 Increase in perenniality of WatLUC sub-catchments

The following maps show the cumulative net change in perennial vegetation cover in WatLUC sub-catchments along river basins. The value shown in each sub-catchment is the net change for the entire area upstream from the outlet of the sub-catchment.

Change in net perennial vegetation cover

Change in net woody perennial vegetation cover





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Appendix E Influence of Loss Estimates of Soil and Vegetation Type and Watertable Depth

This appendix contains a limited number of graphs that show the variation in the annual average loss value with soil and vegetation type and depth to water table. Graphs are shown for land with shallow and deep water tables (2 and >15 m, respectively) for two contrasting sub-catchments, the upper Moorabool (#1) and Muston Creek (#36). Average loss values are plotted for the six most common soil types in each sub-catchment. These are not necessarily the same in each sub-catchment.

Variation reflects the difference in drainage rate (more rapid drainage, generally means increased loss) and soil depth (greater depth measure less loss for deep rooted vegetation types). Shallow water tables provide the opportunity for some perennial vegetation to have net water discharge. (negative loss).



Upper Moorabool sub-catchment (#1). Depth to water table: 2 m (LRFF – low rainfall farm forestry species).





• Upper Moorabool sub-catchment (#1). Depth to water table: >15 m



Muston Creek sub-catchment (#36). Depth to water table: 2 m





Muston Creek sub-catchment (#36). Depth to water table: >15 m



Appendix F Contributions of land use change scenarios to hydrologic change

This appendix contains examples from eight sub-catchments that show the contributions to hydrologic change of various land uses under the base case scenario. The graphs show the incremental rather than cumulative contribution of change in each of the land uses represented. For example, in sub-catchment 1 expansion in hardwood forestry (blue gums) contributed to incremental reductions in total water yield of 2.9, 1.5, 0.2 and 0.2 mm/y (4.9 mm/y in total), respectively, by the 2003, 2010, 2020 and 2030 reporting periods.

The land uses that were selected were the five that had the greatest positive or negative contribution to total sub-catchment yield (the five "main" land uses). Changes in yield are expressed in mm depth equivalents (as is rainfall). The following sub-catchments are included:

- Moorabool basin 1, 3
- Portland coast basin 49
- Lake Corangamite basin 17
- Glenelg basin 64, 65.

- Hopkins basin 36, 38
- Sub-catchment 1. Main land uses broadacre grazing–short growing season (ba_sgs); native vegetation-grassy woodland (nvg_gw); hardwood forestry plantations (for_hw); softwood forestry plantations (for_sw); rural residential-native vegetation (rur_nv).







 Sub-catchment 3. Main land uses – crop; ba_sgs; irrigated horticulture-vegetables (hov_ir); urban, commercial (com).

 Sub-catchment 17. Main land uses – crop; ba_sgs; dairy-short growing season (da_sgs); native vegetation – grassland (nvg_g); for_hw;



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Sub-catchment 36. Main land uses - crop; ba_sgs; da_sgs; nvg_g; nvg_gw.

Sub-catchment 38. Main land uses - crop; ba_sgs; nvg_g; nvg_gw; for_hw







Sub-catchment 49. Main land uses – ba_sgs; da_sgs; nvg_gw; native vegetation-woodland (nvg_w); for_hw.

Sub-catchment 64. Main land uses – crop; ba_sgs; nvg_g; nvg_gw; for_hw.





 Sub-catchment 65. Main land uses – ba_sgs; da_sgs; native vegetation-shrubland (nvg_s); for_hw; for_sw.





Appendix G The ForestImpact Model

G.1 New model developments

The ForestImpact model (Daamen *et al.*, 2001b) has been developed using information from several sources including an investigation of the response of stream flow to the regeneration of Mountain Ash forest (Kuczera, 1985). This original study described changes in average annual stream flow as a function of forest age. ForestImpact draws on Kuczera (1985) and subsequent investigations by a number of authors to provide stream flow response functions for the following forest types:

- Mountain Ash forest (in the Melbourne Water Supply catchments, Otways);
- Mixed Eucalypt forest (in the Otways, south east NSW and north east NSW);
- Snow Gum forest (Victorian Alps);
- Pine Plantation (Tumut NSW, and this study);
- Blue Gum Plantation (this study).

Note that ForestImpact represents the effects of forest age (and management) on *average annual* stream flow.

The ForestImpact model has been updated since Stage 1 of the Water and Land Use Change project and these updates are incorporated into the application of the model here in Stage 2. The representation of Pine Plantations and Blue Gum plantations has also been updated in line with the other changes as described below.

The water use (or evapotranspiration) of regenerating native eucalypt forest has some interesting characteristics. Firstly, in the year after harvesting or fire ForestImpact assumes that forest water use is equal to grassland water use. Thereafter, as a native eucalypt forest grows, the water use increases quickly exceeding the water use of a mature forest after about 7 years. Maximum forest water use typically occurs between years 20 and 30 and thereafter it slowly decreases approaching the mature forest water use asymptotically (at age > 200 years).

Kuczera (1985) introduced a function that did not allow for a large decrease in forest water use in the first years after harvesting or fire. ForestImpact now uses a seven parameter function (Watson *et al.*, 1999) that allows representation of the above features of forest water use as a function of age, including an initial decrease in forest water use.

In Victoria, Forest Plantations of Pine and Blue Gum represent additional forest types that are also considered in the model. These plantations have similarities and differences with the water use of regenerating native eucalypt forest as follows:



- Forest Plantations are harvested relatively young (at about 12 years for Blue Gum and 30 years for Pine). [Therefore it is assumed that water use of forest plantations will not decrease from maximum values once reached even though this was observed in regenerating native forests. This approach is adopted because harvesting at a young age does not allow senescence to occur and, in addition, declining forest water use with age may be a particular characteristic of naturally regenerating eucalypt forests that perhaps does not occur in native pine forests (where they occur overseas).]
- Forest Plantations develop a full canopy quickly (after about 4 or 5 years for Blue Gum and 10-15 years for Pines). This quick development is facilitated by land clearance, regular spacing, use of seedlings (under natural regeneration trees must grow from seed) and other plantation forest management practices.
- The maximum water use of forest plantations is not expected to differ significantly from the maximum water use of native eucalypt forest. Some studies, (e.g, Vertessy and Bessard, 1999), suggest that a mature pine plantation may use more water than a eucalypt forest this distinction is not made in ForestImpact maximum water use of pines and blue gum plantations is assumed to be approximately equal.
- The minimum water use of forest plantations is also not expected to differ from the minimum water use of native eucalypt forest. [In the year that a forest is burnt or harvested/planted the model assumes that water use is equal to grassland for all forest types.]

These characteristics are used below to update the representation of pine and blue gum plantations in the ForestImpact model used for this project.

ForestImpact uses the same 7 parameter function to represent forest water use for all forest types including pine and blue gum plantations. The parameter values used for pine plantations were chosen so that the plantations had the characteristics described above and also had a good correspondence with the data presented by Munday et al. (2001). Figure 10-1 compares the current stream flow response function with the function fitted by Munday et al. (2001). The primary difference is the larger stream flow in the first year or two since the pine seedlings were planted, this was required to make the water use in the first year equal to that of a grassland.





 Figure 10-1. Pine Plantation: comparison of the stream flow response function used in Forest Impact for an annual rainfall of 950 mm/year with the function used by Munday et al. (2001).

Studies by Benyon (2003) and Bosch and von Gadow (1990) are used to characterise the water use of a blue gum plantation as a function of age. Blue gum plantations in the Green Triangle (SW Victoria and SE South Australia) have closed canopies and maximum water use by the 4th or 5th year. This characteristic is supported by the study of eucalypt plantation water use in South Africa by Bosch and von Gadow (1990). They indicate an approximate increase in water use from a grassland initial condition (\approx 800 mm/year) to the plantation water use approximately equal to rainfall (\approx 1200 mm/year) over a similar period. [*Note that there are some important differences in climate between South Africa and Victoria, Australia.*]

The stream flow response functions for Pine and Blue Gum Plantations are shown below (Figure 10-2) for a catchment with an annual rainfall of 1200 mm. Section G.2 below describes the approach to adjustment of the Pine function for a catchment with a rainfall of 950 mm/year (Figure 10-1) to a catchment rainfall of 1200 mm/year (Figure 10-2).





Figure 10-2 Comparison of stream flow response functions for Pine and Blue Gum forest plantations for an annual rainfall of 1200 mm.

The parameter values used to represent five forest types in Forest Impact are given below (Table 10-1). The shape of the functions is shown in Figure 10-3.

Table 10-1. Parameter values used in the stream flow response function (Watson et al., 1999) for the five forest types. Note that the parameter values for the forest plantations are a little inconsistent with the other forest types because of the different shape of the function required.

Forest Type (Annual Rain)	ETp	tp	ETc	tc	ETd	t _d	ETm
	(mm/y)	(years)	(mm/y)	(years)	(mm/y)	(years)	(mm/y)
Mountain Ash (2000 mm)	1500	34.0	800	6.0	400	60.0	300
Mixed Species Eucalypt (1000 mm)	795	16.1	843	6.83	-440	17.1	403
Snow Gum (2475 mm)	1200	5.5	925	1.2	220	100.0	250
Pine Plantation (950 mm)	1200	4.0	1100	5.0	0	1.0	580
Blue Gum Plantation (1200 mm)	1430	10.0	1430	1.6	0	1.0	600





 Figure 10-3. Stream flow response functions for the five forest types adjusted for a rainfall of 1600 mm/year. Note that pine plantations and blue gum plantations are only plotted to 30 years because it is expected that the plantations will be harvested at or before 30 years.

Figure 10-3 shows the stream flow response functions for an annual catchment rainfall of 1600 mm/year, this is a little higher than the highest rainfall of a sub-catchment in the water and land use change study. Section G.2 describes how these functions are scaled for lower sub-catchment rainfalls and bounded by the maximum stream flow (i.e. equal to that of a grassland catchment) and the minimum stream flow ('no flow' conditions).

G.2 Scaling stream flow response functions for rainfall

The stream flow response functions (presented in section) describe the effect of forest age on stream flow for one catchment with a single forest type and a given rainfall. These functions are used to characterise stream flow from forests of the same type in catchments with a range of different average annual rainfalls. This is achieved in the ForestImpact model by using a more general relationship between rainfall and evapotranspiration for mature forest and grassland. The approach used is described below.

Forest and grassland evapotranspiration

Holmes and Sinclair (1986) developed a relationship between mean annual rainfall and run-off from forested catchments and grassland catchments. They examined rainfall/run-off relationships for 19 large catchments in Victoria with mean annual rainfalls ranging between 500 and 2,500 mm and with varied vegetation types. They demonstrated a significant difference between the evapotranspiration of grass and eucalypt forest and developed a set of curves to model the mean

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annual evapotranspiration against mean annual rainfall for forest and grassland. Analysis of independent data sets (Cornish, 1989) supported the result.

This early work and other studies were the starting point for a study by Zhang *et al* (1999). Zhang *et al* (1999) developed a semi-empirical relationship between mean annual rainfall and evapotranspiration. This relationship is shown in Equation G-1.

$$\frac{ET}{P} = \frac{1 + w\frac{E_0}{P}}{1 + w\frac{E_0}{P} + \left(\frac{E_0}{P}\right)^{-1}}$$
 Equation G-1

Where:

ET = actual annual evapotranspiration (mm/year)
P = precipitation (mm/year)
E0 = potential evapotranspiration (mm/year)
w = plant available water coefficient, this represents the ability of plants to store water in the root zone for transpiration (-). Zhang *et al* (1999)
suggest that w should range between 0.5 (short grass) and 2 (forest). For bare soil, w represents the water in the soil that can be evaporated, it is expected that this is around 0.1.

Zhang *et al* (1999) generalised Equation G-1 by replacing E_0 with a constant E_z using a large number of data sets from across the world. Under this interpretation, Ez does not represent potential evaporation it is an approximate maximum forest water use at all sites considered by Zhang *et al*.

$$\frac{ET}{P} = \frac{1 + w \frac{Ez}{P}}{1 + w \frac{E_z}{P} + \left(\frac{E_z}{P}\right)^{-1}}$$
Equation G-2

Where:

ET = actual annual evapotranspiration (mm/year)

P = precipitation (mm/year)

 $E_z = 1410 \text{ (mm/year)}$ for trees and 1100 (mm/year) for grass.

w = plant available water coefficient.

Equation G-2 is used to estimate average annual evapotranspiration of mature forest and grassland as a function of rainfall (Figure 10-4).





• Figure 10-4 Evapotranspiration versus rainfall for forest and grassland (after Zhang et al., 1999).

These functions are used to adjust the stream flow response (as described below) however it is possible to use any other similar functions (for example, Vertessy and Bessard, 1999).

Rainfall Transposition Factor

The stream flow response functions are applied to any catchment by scaling or transposing the function using the difference between the generalised evapotranspiration curves for forest and grassland (above). It is assumed that:

- the grassland curve (Figure 10-4) is the minimum evapotranspiration for any land use, and
- the forest curve (Figure 10-4) represents evapotranspiration of a mature eucalypt forest.

The scaling factor is the ratio of the difference between the forest and grass curves at the rainfall of the catchment in question to the difference between the forest and grass curves at the rainfall associated with the response function. For example, let us consider how the Mountain Ash stream flow response function (fitted to data for a catchment with a rainfall of 2000 mm/year) is used in a catchment with a mean annual rainfall of 1500 mm. The response function is multiplied by a transposition factor. The required factor is explained with reference to Figure 10-5 and is the difference between the grass and forest curves at a rainfall of 1500 mm/year (y) divided by the difference between the grass and forest curves at a rainfall of 2000 mm/year (x).





 Figure 10-5: Forest evapotranspiration versus rainfall for forest and grassland (after Zhang et al., 1999). The differences shown as x and y are used to scale the function fitted to a catchment with a rainfall of 2000 mm (x) to a another catchment with a rainfall of 1500 mm (y).

Limits to the Transposed Streamflow Response Function

There are two constraints or bounds to the streamflow response functions that limit the maximum and minimum ET of a forest, these constraints are detailed below.

The difference between the grassland curve and the forest curve for a given rainfall gives the maximum possible increase in streamflow when a mature eucalypt forest is harvested or burnt. Using the example in Figure 10-5, the maximum possible increase in streamflow between when a mature forest is harvested or burnt would be x. As such the maximum increase in streamflow of the a scaled streamflow response function would be limited to x.

The second constraint is rainfall itself, it is assumed that the forest ET is not able to exceed the mean annual rainfall of a given catchment. This means that any calculated increase in forest ET that exceeds rainfall is truncated.

Example of rainfall adjustment

Figure 10-6 demonstrates the application of the approach described above for adjusting the stream flow response functions to catchment rainfall.





 Figure 10-6 Stream flow response functions for Blue Gum Plantations in catchments with a range of rainfall values.



Appendix H Discussion Paper: Hydrogeology



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Thursday, 2 September 2004

South West Water and Land Use Change project

Discussion paper for Sinclair Knight Merz

1 Introduction

The South West Water and Land Use Change (WatLUC) project is a consultancy being undertaken by Sinclair Knight Merz (SKM) for the Corangamite Catchment Management Authority (CCMA) and the Glenelg Hopkins Catchment Management Authority (GHCMA). The project aims to model the hydrological changes to the landscapes of southwest Victoria under a variety of land-use scenarios.

The initial WatLUC model calculated a water balance for landscape components at the sub-catchment scale using two interrelated models: the forest impact model and the soilflux model (Daamen *et al.*, 2003). The WatLUC model calculates major fluxes into and out of the combined reservoir of surface water and shallow groundwater (SKM 2003). One assumption in the model – that the net movement in the shallow groundwater between sub-catchments is negligible – has been questioned. This brief report was commissioned by Dr Carl Daamen, Environmental Modeller, SKM, to address the issue of inter-catchment groundwater flows.

1.1 WatLUC assumptions

The initial stage of WatLUC modelling made several key assumptions regarding the groundwater systems within each sub-catchment, as listed below (SKM 2003):

- It is assumed that there is a good hydraulic connection between shallow groundwater systems and surface water (streams). Water leaking below the root zone of vegetation into the shallow groundwater systems will quickly (or easily) leave them in the stream network. In Victoria the shallow groundwater systems are generally of low hydraulic conductivity.
- Net groundwater movement in shallow groundwater systems is considered to be insignificant between sub-catchments.
- Recharge of deep groundwater systems is considered to discharge off-shore and does not become part of the water balance in other sub-catchments (unless pumped to the land surface and used for irrigation).
- Stream flow into a sub-catchment is assumed to pass through a sub-catchment without affecting the sub-catchment water balance and without being affected by the sub-catchment water balance.
- The above points result in the change in leakage due to a land use change, being expressed as a change in stream flow and a change in recharge of deep aquifer systems.
- A corollary of the above is that a change in the water balance in one sub-catchment has no significant influence on the water balance in upstream and downstream subcatchments.

The sub-catchments used in the WatLUC model are illustrated overpage (Figure 1), overlain on the groundwater flow systems for the CCMA and GHCMA (Dahlhaus *et al.* 2002).



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2 Discussion

To assist the future development of the WatLUC model, the following discussion raises questions about some of the assumptions in the model. The discussion is not intended to undermine or question the validity of the model, but aims to assist the future development of WatLUC by providing examples of situations where the assumptions may not hold true.

2.1 Groundwater flow between sub-catchments

One difficulty in choosing surface water sub-catchments for modelling groundwater fluxes is that the sub-catchments boundaries rarely match aquifer boundaries. In southwest Victoria the vast majority of drainage is controlled by the geology and geomorphology of the landscapes. Streams often follow geological boundaries, especially those which developed after the widespread disruption to the drainage following the emplacement of the Newer Volcanic Formation. The groundwater flow system on one side of a stream is often different (and disconnected) from that on the other side.

In some cases, the groundwater divide mismatches the surface water divide. The most obvious example is in the area north of Ballarat (Figure 2).



Figure 2. Mismatch of groundwater and surface water divide.

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In the upper Woady Yaloak River and upper Leigh River catchments the drainage divide of the surface water was moved approximately 10 kilometres south of the pre-volcanic divide established in the Pleistocene. The valley flow basalts are hydraulically connected to the underlying deep lead sediments, and the groundwater generally moves north in both groundwater systems, while the surface water moves south.

Other examples of valley flows overlying deep leads, which divert groundwater between sub-catchments, occur south of Williamson's Creek, where groundwater flows from the Leigh River sub-catchment into both the lower Moorabool River sub-catchment and the Native Hut Creek sub-catchment. Similarly the Woady Yaloak deep lead diverts groundwater from the upper Woady Yaloak River sub-catchment into the lower Woady Yaloak River sub-catchment.

Aside from the groundwater being channelled between sub-catchments along the former drainage systems, inter-catchment regional groundwater flows also occur. Regional flow is thought to be dominant for most of the volcanic plains groundwater flow system. The extent to which this occurs is not fully understood and is the subject of a major research project commencing in September 2004 within the CCMA.

Research to date (Thompson 1971, Dickinson 1995, Coram 1996, Blackam 1999) indicates that groundwater flow is relatively continuous in the hydraulically connected flow systems of the Quaternary sediments, scoria cones and stony rises, volcanic plains and Pliocene sands from Lake Martin – Lough Calvert to the Barwon River (Figure 3). Similar inter-catchment flows have been found in the Willaura and Hamilton regions (Bennetts 1999, Bennetts *et al.* 2003).



Figure 3. Inter-catchment groundwater flow (arrowed) in the CCMA volcanic plains.

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The third obvious inter-catchment groundwater flow occurs in the vicinity of the large lakes on the volcanic plains. In particular, the groundwater flow around Lake Corangamite has been the subject of extensive research and investigation (Thompson 1971, Gill 1988, Dickinson 1995, Coram 1996, Coram *et al.* 1998). Although the previous work varies in the detail, the common model is that the lake acts as a large evaporation pump, drawing groundwater towards it from all sides (Figure 4).



Figure 4. Groundwater flow net around Lake Corangamite (Coram et al. 1998).

2.2 Discharge from deeper systems

The assumption that discharge from 'deep' groundwater systems occurs off-shore should also be questioned. It is assumed that in this context, 'deep' groundwater systems are confined aquifers.

Two possible exceptions to this assumption may occur. The first is in the Barwon Downs Graben, where water from the Dilwyn Formation is used to supplement Geelong's urban water supply (but this may be taken into account by the WatLUC model). The second is if deep lead aquifers are considered 'deep' systems. The deep leads flowing south from the Central Highlands contribute to the groundwater flux of the volcanic plains.

2.3 Continuity of stream flow

Although it is probably considered in the WatLUC model, the assumed continuity of stream flow does not hold in catchments where surface water is diverted to other catchments. Examples are the water harvested from the Moorabool River for Ballarat's water supply, most of which is disposed of in the Leigh River and Lake Burrumbeet; the diversion of the Woady Yaloak River into the Barwon River; and the water drained from Lough Calvert into the Birregurra Creek.
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Appendix I Changes in surface water flows with land use change

This appendix provides examples of some of the outputs from WatLUC modelling, as they relate to changes in either total catchment water yield or net surface water yield. A summary of the contents of this appendix are given below:

- Appendix I.1 Examples of changes in total water yield for the sub-catchments included in Appendix E. Graphs plot the change in water yield for the period 1990-2030 for all land use change scenarios.
- Appendix I.2 Maps of change in total sub-catchment water yield from 1990-2030 for the base case scenario. Change in yield is expressed in terms of % mean annual surface water flow, despite the total yield including surface water flows and, in some sub-catchments, recharge to deep aquifers.
- Appendix I.3 Maps of change in surface water yield from 1990-2030 for the base case scenario. Surface water yield is the residual of total yield once recharge to deep aquifers has been allocated (in the relevant catchments). Change in yield is expressed in volumetric terms to indicate the scale of potential change.
- Appendix I.4 Maps of % change in surface water flow upstream from each sub-catchment for 1990-2030. The map shows the incremental effect of land use change on potential river flows moving down a river basin.
- Appendix I.5 Maps of change in volumetric surface water flows upstream from each subcatchment for 1990-2030. The map shows the incremental effect of land use change on potential river flows moving down a river basin.
- Appendix I.6 Maps showing the sum of current surface water use and potential change in surface flow with land use change upstream from each sub-catchment for 1990-2030. Use plus changed flow from land use change is expressed relative to the SDL. The map shows the incremental change in stress moving down each river system.
- Appendix I.7 Maps show for each sub-catchment the sum of potential flow reductions due to current water use and diversions and those predicted to occur with land use change (base case scenario), expressed as a % of the SDL. The maps provide an indication of the sources of flow stress in a river basin.
- *Appendix I.8* Maps show how the flow-related stresses in Appendix I.7 accumulate along the course of rivers and river basins.

I.1 Changes in total sub-catchment water yield with time

With Figure 5-1, the following graphs plot the accumulated change in sub-catchment water yield from 1990 to 2030 for the sub-catchments considered in Appendix E (the graphs in that section

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only plotted incremental change). Data for all scenarios are included. Change is expressed in terms of percentage change in total sub-catchment flow. The captions indicate the mean annual flow (not adjusting for current use) in the sub-catchment in mm. Changes relate to potential flows leaving the sub-catchment and do not account for within sub-catchment storages or diversions.



Sub-catchment 3 (mean annual flow = 21 mm)







Sub-catchment 36 (mean annual flow = 88 mm)









Sub-catchment 49 (mean annual flow = 75 mm)







Sub-catchment 65 (mean annual flow = 92 mm)

Note that under the high forestry scenario, this sub-catchment is predicted to have a reduction in streamflow that exceeds 100%. This is the result of the two numbers comprising the % flow change being obtained from different sources and derived in different ways (MAF being derived from SDL calculations, changes in streamflow from WatLUC methods).



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I.2 Change in total water yield from 1990: base case scenario (as % of mean annual flow)

The maps show reduction in total water yield (sum of surface water flow and deep aquifer recharge) for the base case scenarios. Changes in yield are expressed as a percentage of the mean annual (surface water) flow (MAF) generated in the sub-catchment. Changes relate to potential flows leaving the sub-catchment and do not account for within sub-catchment storages or diversions. With the scale of change in yield used in the map, there is little difference between most of the land use change scenarios. At most, two or three sub-catchments shift up or down a flow change class.

2003:

2010:

Water and Land Use Change Sub-catchments: % change in sub-catchment water yield.





+/-5% indicates a range in % change in sub-catchment water yield of between -5 and +5%.

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2020:

2030:







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I.3 Change in surface water flows 1990-2030 under base case scenario (as volumetric annual flow)

This series of maps shows the way in which surface water flows from each sub-catchment would change with each land use change scenario. The changes predicted take no account of the current use of water within the sub-catchment.





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2020

2030



Water and Land Use Change: Change in sub-catchment surface water yield



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I.4 Change in % flow upstream from each sub-catchment under base case scenario: 1990-2030

This series of maps shows the accumulating effect of flow reductions moving along river systems. Maps indicate the percentage change in potential surface water flows averaged over the entire catchment area upstream of the outlet of the particular sub-catchment. Averaging over increasingly large areas tends to mask extreme flow reductions in some individual sub-catchments

2003



2010



60 Kilometers

+/-5% indicates a range in % change in flow upstream of between -5 and +5%.

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-15-25%

15-100%



2020

2030



Water and Land Use Change: % reduction in flow upstream from sub-catchment



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I.5 Cumulative change in volumetric flow along river basins under base case scenario: 1990-2030 This series of maps shows the accumulating effect of flow changes in volumetric terms moving along river systems.



+/-2.5 GL/y indicates a range in change flow of between -2.5 and +2.5 GL/y.

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2020





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I.6 Change in flow as a percentage of the sustainable diversion limit in each sub-catchment for the base case scenario: 1990-2030 The map expresses change in flow as a percentage of the SDL at a sub-catchment level. The data do not allow for diversions and storages. Note that the effect of flow reductions greater than the SDL are experienced downstream of the highlighted catchment. Current use as a % of SDL is shown in Appendix A. Change in flow divided by two to allow for SDL applying only to July-October flows.



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2020

2030





Water and Land Use Change: Reduction in flow as % SDL

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I.7 Sum of current use and estimated reductions in surface water flows as a % SDL: 1990-2030 base case scenario

The maps show for each sub-catchment the sum of potential flow reductions due to current water use and diversions and those predicted to occur with land use change (base case scenario), expressed as a % of the SDL. Change in flow divided by two to allow for SDL applying only to July-October flows. The maps provide an indication of the sources of flow stress in a river basin.



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I.8 Cumulative sum of current use and estimated reductions in surface water flows: 1990-2030 base case scenario

The maps show how the flow-related stresses in Appendix I.7 accumulate along the course of rivers and river basins. Current use and change in flow with land use are added for the entire area above the outlet of each sub-catchment, halved (to bring into line with SDL) and then divided by the SDL for that same area.



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I.9 Changes in flow stress ranking indices with 2030 base case land use change scenarios

This series of maps show the FSR winter, summer and annual indices for each sub-catchment under the base case scenario. They also show the difference between the FSR index for the current flow regime and base case scenario. FSR calculations could not be performed in the sub-catchments coloured yellow.

Base case land use change scenario: winter flow indices



Difference in FSR between current water regime and that with base case land use change scenario: winter flow indices



Water and Land Use Change: Changes in flow stress index

FSR values range between 1 (fully natural flow regime) and 0 (extreme flow alteration)

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Base case land use change scenario: summer flow indices

 Difference in FSR between current water regime and that with base case land use change scenario: summer flow indices



Water and Land Use Change: Flow stress ranking - summer index



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Base case land use change scenario: annual flow indices

• Difference in FSR between current water regime and that with base case land use change scenario: annual flow indices



Water and Land Use Change: Flow stress ranking - annual index

Water and Land Use Changes in flow stress index

60 Kilometers

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-0.6 - -0.4

-0.4 - -0.2 -0.2 - -0.05

-0.05 - 0.05

Yellow shaded sub-catchments have no data

0.05 - 0.2



Appendix J Changes in recharge to deep aquifers with land use change



Change in volumetric recharge to groundwater from each sub-catchment: 1990-2030

2003

2010



Water and Land Use Change Sub-catchments: reduction in recharge to deep aquifers: 2010



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2020

2030

Water and Land Use Change Sub-catchments: reduction in recharge to deep aquifers: 2030







Appendix K Predicting the hydrologic response to land use change

Regression analysis was used to identify the land use changes and other factors that most influenced hydrologic change. Total sub-catchment water yield (TSWY, expressed in mm) was used as the independent variable as it is independent of sub-catchment area and the partitioning of hydrologic change between surface water and groundwater. Changes in woody vegetation cover (pfw) were the aggregate of change in the proportion of a sub-catchment under softwood and hardwood plantations, forest and woodland EVCs and woodlands on rural residential land. Changes in perennial pasture and grassland cover were the aggregate for perennial pastures in

The resulting regression co-efficients and respective level of statistical significance are given in the table below. Annual rainfall and cropping land use change were not statistically significant coefficients in the regression equation. The equation explained over 95% of the variation in total surface water yield predicted by the WatLUC modelling process.

Term	Definition	Regression coefficient	P Value		
TSWY	Total sub-catchment water yield (mm)	Independent variable			
Intercept		-7.7816	0.035		
PWF	Proportion of sub-catchment under hardwood and softwood plantations, forest and woodland EVCs and woody vegetation on rural residential land	-199.48	<0.001		
PP	Proportion of sub-catchment under perennial dairy or broadacre pasture and grassland and grassy woodland EVCs	-23.655	<0.001		
URB	Proportion of sub-catchment under urban land uses	292.90	<0.001		
СОМ	Proportion of sub-catchment under commercial land uses	372.28	<0.001		
CRP	Proportion of sub-catchment under cropping	-4.9108	0.398		
Rainfall	Sub-catchment average annual (mm/y)	0.004544	0.209		

Table K-1 Regression coefficients and statistics for multiple regression analysis of total sub-catchment surface water yield with rainfall and proportional land use change.

The two not statistically significant terms were then dropped from the regression equation and a new multiple regression derived. The equation is given below. All coefficients are statistically significant at least at the 0.001 level. The r^2 value is 0.947, indicating that equation K-1 explains almost 95% of the variation in total surface water yield predicted by WatLUC modelling.

TSWY = -3.9956 - 201.18 PFW - 28.071 PP + 256.87 URB + 349.04 COM(K-1)

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Residual plots for the four terms in equation K-1 are given in the Figure K-1, below. The average and median values of the residuals are 0.0000 and 0.0390, respectively. The residual is greater than 5 mm/y total water yield or less than -5 mm/y for only 7 of the 66 WatLUC sub-catchments.



• Figure K-1 Residual plots for terms in equation K-1

There appears to be little bias in the residuals in relation to any of the terms in equation K-1, nor is there any obvious bias in the residuals when plotted against the WatLUC total surface water yield estimates.

The independence of Equation K-1 of rainfall and catchment size and its high correlation coefficient suggest that it could be a useful tool in predicting the hydrologic impacts of other land use change scenarios in the WatLUC study area.



Equation 1 indicates that for each 10 percentage point change in sub-catchment land use, the corresponding change in total sub-catchment water yield would be:

- -20.9 mm/y for an increase in woody vegetation cover;
- -2.8 mm/y for an increase in perennial pasture or grassland cover;
- +25.7 mm/y for an increase in urban land use;
- +34.9 mm/y for an increase in commercial land use.



Appendix L Identifying Hot Spots of Hydrologic Change in South-West Victoria

WatLUC provides the opportunity to identify areas where the potential level of land use and/or hydrologic change is such that they warrant further attention. Several criteria could be used to identify such hot spot areas, including those with a:

- large net increase in perennial vegetation cover;
- large net increase in woody vegetation cover (forestry plantation or native vegetation);
- large net reduction in potential streamflow generated within a sub-catchment and/or in the catchment above a sub-catchment
- large net reduction in potential deep aquifer recharge;
- substantial current and/or future flow stress.

Data that are relevant to these criteria and have been presented in previous appendices were used to identify hot spot areas. Each of the 66 sub-catchments was assessed against a total of seven criteria (Table L-1) using the classification schemes applied to the maps in which the data were represented. Classes were arranged so that the highest number was given to sub-catchments with the greatest level of or potential for hydrologic stress. The class numbers for each criteria were then added and this number ranked among the corresponding numbers for all of the sub-catchments. Two ranking schemes were developed, one applying to both land use and hydrologic change criteria and the other applying only to hydrologic change criteria. The process has only been applied for the base case land use change scenario.

Maps (Figure 6-2) showing the ranking under each scheme have been produced to highlight hot spot areas.



#	Perennial cover	Woody perennial	Sub-cat SW flow	Sub-GW recharge	Upstream SW flow	Current annual FSI	Change in annual FSI	Hydrol & LU change ranking	Hydrol change ranking
1	4	3	3	1	4	4	2	24	25
2	2	2	2	1	3	4	2	49	40
3	1	3	1	1	1	3	1	65	66
4	4	2	2	1	4	1	2	49	57
5	3	3	2	1	4	1	2	49	57
6	2	3	1	1	3	3	3	49	51
7	4	2	3	1	3	2	3	39	40
8	1	3	3	2	4	2	3	39	25
9	4	2	3	1	5	1	2	39	40
10	3	3	2	1	3	2	3	43	51
11	1	3	1	1	1	3	3	62	61
12	4	3	2	1	5	2	3	31	33
13	4	2	3	1	4	3	3	31	25
14	6	2	3	1	5	3	3	14	15
15	5	2	3	1	4	3	3	24	25
16	3	2	3	2	4	1	2	43	40
17	5	2	3	1	5	3	3	18	15
18	2	3	2	1	4	2	3	43	40
19	4	3	4	1	5	2	3	18	15
20	5	3	3	2	4	3	3	14	15
21	2	2	2	1	3	2	2	57	57
22	2	2	2	2	3	1	2	57	57
23	2	2	3	1	3	3	2	49	40
24	2	3	3	2	3	2	2	43	40
25	2	2	2	2	3	3	2	49	40

 Table L-1 Identification of hydrologic hot spots²¹ for WatLUC sub-catchments. Numbers in table represent the map class for each criterion.

²¹ # - Sub-catchment number; Perennial cover – 2030 sum of perennial pasture, grassland and grassy woodland EVCs and plantations, forest and woodland EVCs and revegetation on rural residential land; Wood perennial – perennial cover, but without non-woody vegetation types; Sub-cat SW flow – 1990-2030 volumetric change in potential surface water flow generation in sub-catchment; Sub-GW recharge – 1990-2030 volumetric change in potential deep aquifer recharge in sub-catchment; Upstream SW flow – 1990-2030 % change in total catchment area above sub-catchment outlet; Current use % SDL – current annual water diversions and usage as % of SDL; Use & LU change %SDL – sum of current use and 1990-2030 change in potential surface water flows expressed as % SDL; Hydrol & LU change ranking – ranking of sum of classes of hydrologic scores only.



#	Perennial cover	Woody perennial	Sub-cat SW flow	Sub-GW recharge	Upstream SW flow	Current annual FSI	Change in annual FSI	Hydrol & LU change ranking	Hydrol change ranking
26 ²²	2	3	2	2	3	3	2	43	40
27	2	3	2	1	3	1	2	57	61
28	2	2	2	1	3	3	2	56	51
29	2	3	2	2	4	1	3	43	40
30	4	3	3	2	4	1	2	36	40
31	1	2	2	1	2	1	2	65	65
32	1	2	2	1	3	3	2	57	51
33	2	2	2	1	3	1	2	62	61
34	2	2	2	1	3	1	2	62	61
35	3	2	4	1	5	2	3	31	15
36	5	2	4	1	5	3	2	18	15
37	3	3	3	1	6	3	3	18	10
38	4	3	4	1	6	3	3	10	5
39	3	2	3	1	5	3	4	24	10
40	5	3	4	1	6	3	2	10	10
41	5	2	3	1	4	3	2	31	33
42	6	2	4	1	4	3	2	18	25
43	5	3	3	1	4	3	2	24	33
44	5	2	4	1	4	3	2	24	25
45	6	2	4	1	4	2	3	18	25
46	3	2	3	1	4	3	2	39	33
47	6	2	4	1	5	3	2	14	15
48	3	3	3	1	4	2	3	36	33
49	6	4	5	2	6	1	4	4	4
50	3	3	3	1	4	2	3	36	33
51	6	4	5	1	6	2	3	5	5
52	6	3	4	1	5	2	3	10	15

²² # - Sub-catchment number; Perennial cover – 2030 sum of perennial pasture, grassland and grassy woodland EVCs and plantations, forest and woodland EVCs and revegetation on rural residential land; Wood perennial – perennial cover, but without non-woody vegetation types; Sub-cat SW flow – 1990-2030 volumetric change in potential surface water flow generation in sub-catchment; Sub-GW recharge – 1990-2030 volumetric change in potential deep aquifer recharge in sub-catchment; Upstream SW flow – 1990-2030 % change in total catchment area above sub-catchment outlet; Current use % SDL – current annual water diversions and usage as % of SDL; Use & LU change %SDL – sum of current use and 1990-2030 change in potential surface water flows expressed as % SDL; Hydrol & LU change ranking – ranking of sum of classes of hydrologic scores only.



#	Perennial cover	Woody perennial	Sub-cat SW flow	Sub-GW recharge	Upstream SW flow	Current annual FSI	Change in annual FSI	Hydrol & LU change ranking	Hydrol change ranking
53 ²³	1	2	2	1	3	2	3	57	51
54	3	2	3	1	3	2	2	49	51
55	5	2	4	1	4	1	3	31	33
56	5	2	4	1	4	2	3	24	25
57	5	4	6	1	4	2	3	8	10
58	5	4	6	5	4	3	2	3	3
59	3	4	5	3	4	2	3	10	5
60	4	2	3	1	5	3	3	24	15
61	5	3	4	1	5	3	2	14	15
62	6	4	4	1	7	2	3	5	5
63	6	3	4	4	4	3	2	7	5
64	6	3	4	2	5	2	3	8	10
65	5	6	4	5	7	2	4	1	1
66	5	4	4	6	6	2	3	2	2

²³ # - Sub-catchment number; Perennial cover – 2030 sum of perennial pasture, grassland and grassy woodland EVCs and plantations, forest and woodland EVCs and revegetation on rural residential land; Wood perennial – perennial cover, but without non-woody vegetation types; Sub-cat SW flow – 1990-2030 volumetric change in potential surface water flow generation in sub-catchment; Sub-GW recharge – 1990-2030 volumetric change in potential deep aquifer recharge in sub-catchment; Upstream SW flow – 1990-2030 % change in total catchment area above sub-catchment outlet; Current use % SDL – current annual water diversions and usage as % of SDL; Use & LU change %SDL – sum of current use and 1990-2030 change in potential surface water flows expressed as % SDL; Hydrol & LU change ranking – ranking of sum of classes of hydrologic scores only.