Australian Government
Bureau of Rural Sciences

Water 2010 Technical Paper 5

Investigating land use-change-scenario impacts: potential effects of reforestation on water yield in the Upper Murray River Basin

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Foreword

Water issues are now considered among the most important drivers and limitations for natural resource management in Australia. This includes management of biodiversity, primary production and environmental hazards like salinity and drought, through to urban and rural water supplies. A better understanding of water availability is needed across the entire continent, and is relevant to the implementation of key government policies such as Exceptional Circumstances and the National Water Initiative (NWI).

In 2004, the Bureau of Rural Sciences (BRS) recognised that Australia had no comprehensive and consistent source of information on the dynamic water balance, that is, on the spatial and temporal relationships between rainfall, evaporation, transpiration, drainage to ground and surface water, and runoff to rivers and storages. Addressing this fundamental knowledge gap became the primary focus of a project known as Water 2010.

Water 2010 is a BRS driven research collaboration, designed to address the information needs of the National Water Commission (NWC), and to support the Department of Agriculture, Fisheries and Forestry (DAFF) in developing sound water policy. The project is designed to capture information on the water balance at a variety of scales, investigate the consequences for water resources of likely or desired changes in land use, population growth, climate and water policies and practices, and examine the potential impacts of these scenarios on communities, industries and regions to help identify the challenges for industries and regions and suggest opportunities and trade-offs.

Modelling the dynamics of the whole water cycle at a national scale with the capacity to model land cover and land use effects on the water balance was recognised as being critical to the goals of Water 2010.

This paper is the fifth in a series of Technical Papers describing the progress and outputs of the Water 2010 project. The paper describes an analysis of water yield impacts in the Upper Murray River Basin under scenarios of expanding levels of plantation forestry. The work was aimed at testing the BRS steady-state water balance model and improving understanding of the relative influence of landcover type on water yield in catchments that provide significant stream flow to the Murray-Darling Basin. The work also estimated landcover change impacts on water yield in "dry" and "wet" years relative to years with approximately average rainfall.

BRS gratefully acknowledges the support of DAFF and the NWC in this Australian Government work.

Dr Colin J. Grant
Executive Director
Bureau of Rural Sciences

Executive summary

National water balance information need

The BRS Water 2010 project is primarily designed to address the information needs of the NWC with respect to specific components of the NWI and to provide information needed by DAFF to develop sound water reform policy in a changing physical and social environment.

Study aim

The aim of this study was to quantify the impact on water yield of possible and likely land use-change-scenarios (reforestation) in the Murray-Darling Basin, with attention given to relative impacts in wet and dry seasons.

Catchment selection

The Upper Murray River Basin was selected for investigation owing to the possibility of plantation forestry expansion in this area and the high relative contribution of this basin to River Murray flows. Twelve catchments were identified for particular attention based on the presence of pasture land that could be planted for commercial forestry, and the likely affordability of the land for commercial plantation forestry.

Reforestation and climate scenarios

Having run the water balance model under current land use conditions, all pasture land outside National Parks in the selected catchments was reassigned a plantation forestry classification and the model re-run. In addition to average annual rainfall, climate inputs of two-thirds average rainfall and one-and-a-half times the average rainfall were used to compare reforestation impacts on water yield in relatively dry years and in relatively wet years.

Reforestation impacts on water yield

The greatest impacts from reforestation of pasture land, in terms of ML per hectare reductions in yield, were in the lower and middle Mitta Mitta River catchments, with reductions under average rainfall conditions of 1.2 to 1.3 ML per hectare.

Impacts in dry and wet years

Under dry conditions, the greatest impacts were in the Cobungra River and Big River catchments with yield reductions of 0.7 to 1.0 ML per hectare. Under wet conditions, the greatest impacts were in the Lower Mitta Mitta River and Corryong Creek catchments with yield reductions of around 1.5 ML per hectare.

Impact of forecast plantation expansion

A forest industry-based forecast of 30,000 ha of new plantation in the Upper Murray River Basin was estimated to reduce water yield by between 25 and 35 GL/year depending on the location of the additional plantations, under average rainfall conditions (0.9% to 1.3% of average annual yield). This equates to a reduction in yield of around 1.0 ML per hectare on the reforested land. In low rainfall years, forecast new plantations were estimated to reduce yield by 12 to 17 GL per year (1.4% to 1.9% of yield in low rainfall years). Yield reduction in wet years was estimated to be between 0.5% and 0.7%.

Contents

1. Introduction

The Water 2010 project and the National Water Initiative

Water 2010 is a multi-year project being conducted by BRS to help address the information needs of the NWC with respect to specific components of the NWI, and also to provide information needed by DAFF to develop sound water reform policy in a changing physical and social environment in Australia.

The project aims also to assist in designing, implementing and monitoring the effects of policy instruments intended to meet national and regional community water goals and aid and encourage the use of water information to make planning decisions at the catchment scale (e.g. landscape management, catchment water plans, community impact assessments).

The first year of the project had the goal of capturing information on the water balance (water availability, reliability and use) at the finest scale possible for the continent. The aim was to understand and model the dynamics of the whole water cycle, including all major flows (rain, transpiration, soil evaporation, runoff, deep drainage, extraction/irrigation). The approach needed to have the capacity to allow analysis of issues of effects of climate (variability, change) and land (use, management).

This component of the work has now largely been completed, though validation of the accuracy of the information is constantly ongoing. With this information, the project aimed to investigate the impact of likely or desired changes in land use, demography, climate and policies/practices on water resources and identify the challenges (risks and opportunities) for communities, industries and regions, to underpin policy development.

Parties to the NWI have recognised that a number of land use change activities have potential to intercept significant volumes of surface and/or ground water now and in the future. Examples of such activities that are of concern, many of which are currently undertaken without a water access entitlement, include:

i) farm dams and bores;

ii) intercepting and storing of overland flows; and

iii) large-scale plantation forestry.

Parties to the Initiative also recognised that if these activities are not subject to some form of planning and regulation, they present a risk to the future integrity of water access entitlements and the achievement of environmental objectives for water systems.

It is an intention of the NWI therefore to assess the significance of such activities on catchments and aquifers, based on an understanding of the total water cycle. The Parties to the NWI agreed to implement measures in relation to water interception on a priority basis, including identifying significant interception activities and estimating the amount of water likely to be intercepted (IGA on a National Water Initiative 2004).

A CSIRO modelling study of the Murrumbidgee catchment (Best *et al*. in press) assumed the area of plantations there would increase by 30,000 hectares. The maximum basin-wide impact on water use was found to be between 0.2% and 0.7% of average annual flow, and would most likely be in the lower half of that range.

This paper describes work conducted by BRS, in association with scientists from CSIRO Land and Water on quantifying the impact on water yield of possible and likely land use-change-scenarios (reforestation) in selected catchments in the Upper Murray River Basin.

The study aimed to achieve the following objectives:

1. the transfer of knowledge between CSIRO and BRS on catchment water balance modelling and model calibration techniques currently being investigated by both agencies, and,

2. quantifying the impact on water yield of possible and likely land use-change-scenarios (reforestation), with particular attention to quantifying the impact of seasonal rainfall variability on water yield (dry and wet seasons).

Some hydrological principles

The general pattern of movement of rainfall through a catchment is shown in Figure 1. The proportion of rainfall used by plants depends on soil type and depth, plant type, condition and stage of plant growth and crop management. Annual crops and pasture use less water than perennial vegetation, including trees, primarily because of their shorter growing seasons and shallower root systems. The canopies of native and plantation forests intercept more rainfall than pastures or other crops, which adds to their higher evapotranspiration[1].

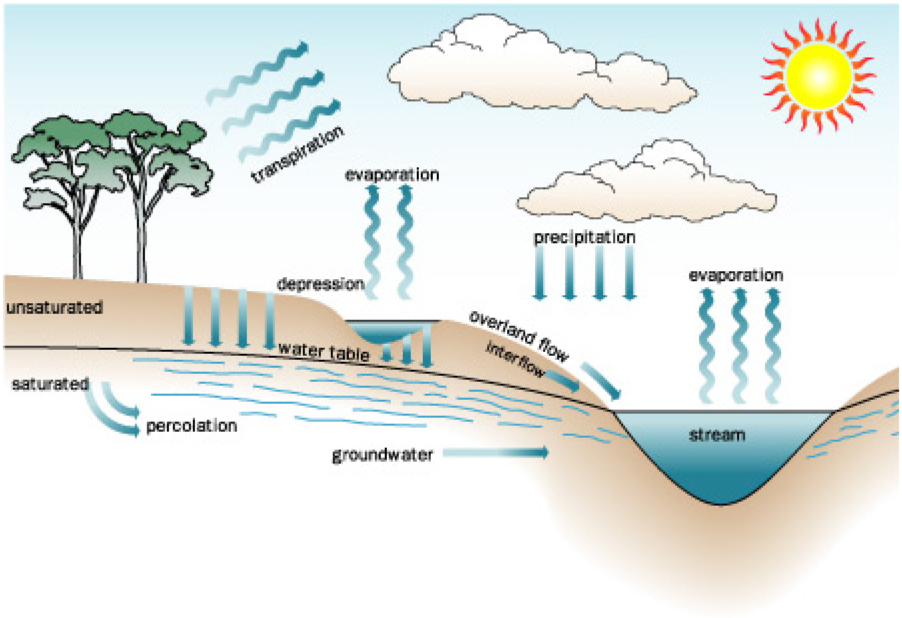

Figure 1. The hydrological cycle of water through the environment (Source: Tasmania State of the Environment Report)

Runoff and stream flow increase when forests are cleared to make way for farming, as occurred over large areas of Australia following European settlement. Until the 1980s, most plantations were pines established on native forest sites. Since the 1980s, most plantations–pines and eucalypts–have been established on sites from which the forest was cleared many years previously to provide farmland.

Runoff and stream flow decrease following reforestation of farmland. Data from many published studies show that the amount by which it decreases depends on rainfall (Figure 2).

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1 Evapotranspiration is the sum of water vapour that diffuses into the atmosphere from vegetation, soil and water surfaces.

For example, where mean annual rainfall is 1,000 mm/year, runoff decreases by an amount equivalent to 200 mm/year on average[2]. The change in a particular location will also depend on soil type, topography, position of the plantation in the landscape and the annual distribution of rainfall.

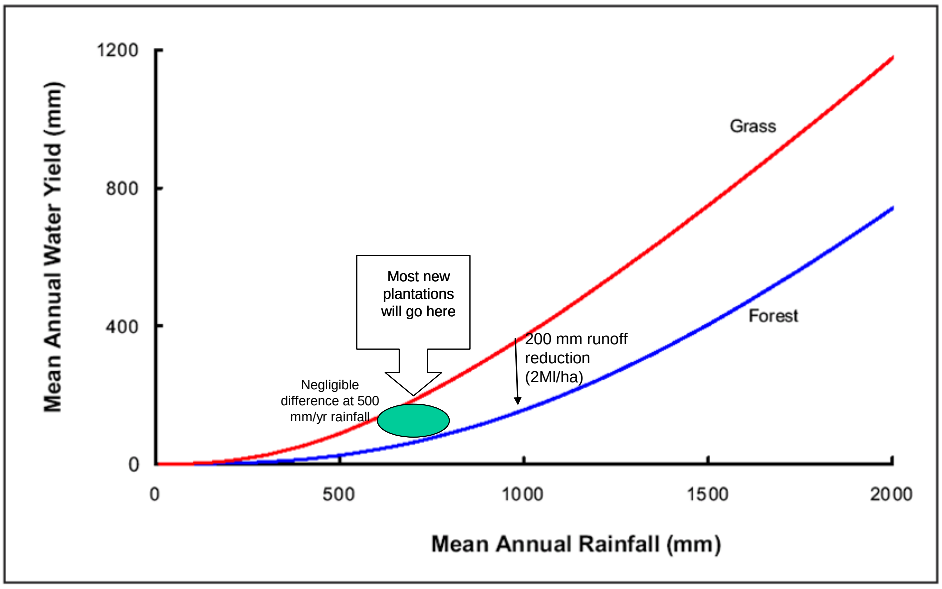

Figure 2. Stream flow is higher from grassed catchments than forests. Source: adapted from Zhang et al. 2003

2 100 mm of rainfall equates to 1 megalitre per hectare.

2. An average annual steady-state water balance model

Modelling methods

The steady-state catchment water balance modelling approach used in this investigation is based on the work of Fu (1981), as reported by Zhang *et al.* (2004 and in press). Under this approach, precipitation is equal to total evaporation (soil evaporation and transpiration) plus runoff (as surface/sub-surface runoff) and drainage to below the root zone.

$$P = E + R + D$$

Where:

P = precipitation

E = actual evapotranspiration

R = surface/sub-surface runoff

D = deep drainage

Actual evapotranspiration is calculated in the model using the following equation from Fu (1981):

$$E = \left(1 + \frac{E_0}{P} - \left(1 + \left(\frac{E_0}{P}\right)^{\alpha}\right)^{\frac{1}{\alpha}}\right)P$$

Where:

E = evapotranspiration

E_0 = potential evapotranspiration

P = rainfall

α = plant available water coefficient

Evaporation is determined by water supply (rainfall) in dry environments and energy supply (radiation) in wet environments. A single-parameter hyperbolic function interpolates between dry (rainfall limited) and wet (energy limited) total evaporation rates. The value of this parameter (α) describes the influence of catchment land characteristics on actual evapotranspiration.

Deep drainage is calculated using a rule-based algorithm from Raupach *et al.* (2001):

$$D = \left(M_{nc}\left(1 - F_c\right) + M_c F_c\right)\left(M_{sa} F_{sa} + M_{si} F_{si} + M_{cl} F_{cl}\right) P_{all}$$

Where:

D = drainage flux

M_c, M_{nc} = cropping and non-cropping multipliers, which take the values of 3 and 1 respectively

F_c = cultivation fraction, which is 1 when the land use is cropping, cotton or sugarcane, else 0

M_{sa}, M_{si}, M_{cl} = sand, silt and clay drainage multipliers, which take the values of 0.02, 0.015 and 0.01 respectively

F_{sa}, F_{si}, F_{cl} = sand, silt and clay fractions, which sum to unity in each grid cell

P_{all} = precipitation plus irrigation

Runoff is calculated as the balance after rain-based deep drainage and evapotranspiration are subtracted from precipitation:

$$R = P - E - D$$

Where:

R = surface and sub-surface runoff

E = rain-based evapotranspiration,

D = rain-based deep drainage

Model input data

The model required gridded inputs of land cover, precipitation, potential evapotranspiration (PET), soils and land cover. Rainfall data were obtained from the Bureau of Meteorology (BoM) based on data from approximately 6000 rainfall stations over the 30-year period 1961-1990. These grided data were generated using the Australian National University (ANU) 3-D spline surface fitting algorithm at a resolution of 0.025 degrees (approximately 2.5 km). As part of the 3-D analysis process, a 0.025 degree resolution digital elevation model was used (BoM, 2000).

Potential evaporation data were obtained from CSIRO Land and Water Division who generated national mean monthly potential evaporation grids using the Priestley-Taylor method on data from the period 1980-1999 for use in the BiosEquil model (Raupach *et al*. 2001). The rationale for this was that when a sufficiently large region is well supplied with water, the total evaporation is determined only by the available radiant energy and is equal to the Priestly-Taylor evaporation rate. These grids therefore, provide an estimate of evapotranspiration from a large irrigated area under no water shortage. The grid resolution is 0.05 degrees (approximately 5 km).

Soils data were obtained from the National Land and Water Resources Audit (NLWRA) based on observations from CSIRO and state soil agencies. The proportion of sand, silt and clay in each horizon is provided in the form of national 0.01 degree (approximately 1 km) grids which have been interpolated from polygon data. For the catchment water balance model, a single value for the proportion of sand, silt and clay in each grid cell was calculated by taking the average of the proportions in each of the two soil horizons weighted by the thickness of each horizon.

A new Australian land cover map was generated from a number of sources including:

- the catchment-scale land use at a cell size of 50 m and currency of 1999 collected by state agencies according to the Australian Land Use Mapping program,
- regional-scale land use data at a cell size of one km, and modelled using the SPREAD II method, which constrains the classification of AVHRR NDVI data for

1996-97 and 2000-01 (for the Murray-Darling basin) to Australian Bureau of Statistics agricultural census data,

- National Forest Inventory forest and plantation types at a cell size of 250 m and currency of 2003,
- TOPO250K data from Geoscience Australia at cell size of 250 m and currency of 2005,
- MODIS NDVI data at a cell size of 250 m and currency of 2003.

These data were prioritised, in terms of scale and currency, and combined to attribute each cell with the best available data. The data were then converted into Albers projection and re-sampled to one km resolution (Figure 3).

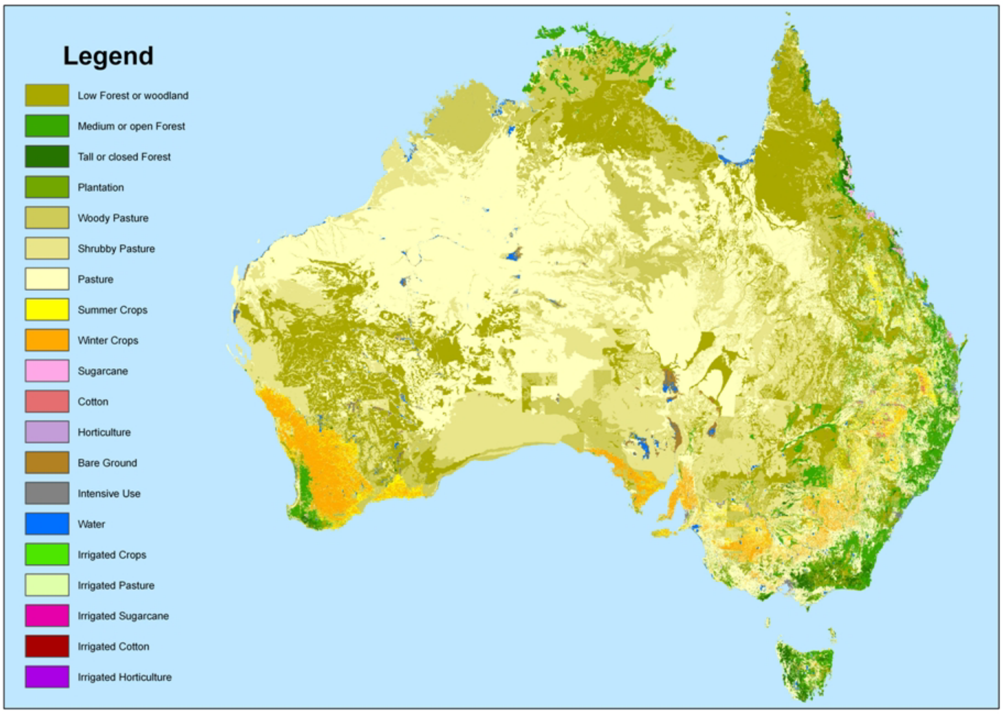

Figure 3. Water 2010 Australian land cover map

Model parameter estimation

The gridded national land cover data were categorised into 15 classes for use in the catchment water balance model (Table 1). A calibration routine was developed that adjusted the land class specific plant available water coefficients (α) and compared mean annual runoff coefficients from the resulting water balance with those in the Peel *et al.* (2000) observed runoff dataset. Fixed amounts (eg 0.1, -0.1) were added to an initial set (grid) of α plant available water coefficients in a loop that calculated the RMS error from the 2 sets of runoff coefficients. In more detail, the loop for each adjustment was:

1. Add the constant value to all cells overlying the Peel polygons in the α grid.
2. Calculate E, D and R over all Peel cells.
3. Calculate the average R, D and P for each Peel polygon.
4. Calculate the runoff coefficient for each peel polygon as: (R+D)/P (this accounts for baseflow by assuming it equals D).

5. Calculate the RMS error between the calculated and Peel's mean annual runoff coefficients.

The best overall RMS error result for average annual runoff was obtained using α values ranging from 2.4 for bare ground to 3.4 for closed forest (0.08197 from 330 sub-basins). However, examination of modelled runoff results for catchments beyond the geographic and climatic space represented by the 330 catchments in Peel *et al.* (2000) suggested that on a national scale this range of parameters was too constrained. The best national results were obtained using values ranging from 2.0 to 4.0 as shown in Table 1.

Table 1. Land cover classes utilised in the catchment water balance mode

Land class	α value	Land class	α value
Tall or closed forest	4.0	Summer crop	2.5
Plantation forest	4.0	Cotton	2.5
Medium or open forest	3.8	Native and modified pasture	2.4
Perennial horticulture	3.3	Winter crop	2.3
Low forest / woodland	3.1	Urban	2.2
Sugarcane	2.9	Water	2.1
Woody pasture	2.6	Bare ground	2.0
Shrubby pasture	2.6		

3. Catchment Selection and Model Scenarios

Catchments of the Upper Murray River Basin were selected for investigation owing to the possibility of plantation expansion in this area and also to the relatively high contribution of these catchments to River Murray flows. Runoff from the Upper Murray River Basin comprises some 25 percent of all flow into the Murray River, excluding that from the Darling River.

There were 12 catchments identified for particular attention based on a combination of:

i) the presence of pasture land that could be planted for commercial plantation forestry (ie, outside of National Parks), and,

ii) the likely affordability of the land for commercial plantation forestry – for example, a number of small catchments comprising the Murray River flats just north and east of Corryong (see Figure 2 below) were considered too valuable as agricultural land to be realistically accessible to plantation forestry interests.

The 12 catchments are listed in Table 2 below. The BRS water balance model was initially run for these catchments using their current land use classifications (see Figure 4) and average annual rainfall data to provide a current or "base" water yield result. All land classified as pasture outside of National Parks was then reassigned a plantation forestry classification in the land use grid. The consequence of this change on plantation area within each catchment is shown under the "Max. scenario plantation area" column in Table 2. The water balance model was then run again using this new land use grid. This entire operation was repeated using two-thirds average annual rainfall and one-and-a-half times average annual rainfall to compare impacts of land use change on water yield in relatively dry years and in relatively wet years.

Table 2. Current forest plantation extent and maximum reforestation scenario plantation extent in the selected catchments in the Upper Murray River Basin

Catchment description	Catchment area (ha)	Current plantation area (ha)	Max. scenario plantation area (ha)	Maximum potential plantation increase (ha)
Tumbarumba Creek	45,000	3,400	10,100	6,700
Maragle Creek	28,500	1,000	9,300	8,300
Tooma River	54,000	600	2,100	1,500
Cudgewa Creek	82,200	6,400	27,300	20,900
Corryong Creek	98,300	100	20,200	20,100
Lower Mitta Mitta River	83,000	1,000	22,700	21,700
Middle Mitta Mitta River	89,000	200	1,000	800
Snowy Creek	43,100	0	1,800	1,800
Morass River	104,600	0	19,500	19,500
Big River	51,200	0	1,600	1,600
Cobungra River	40,400	0	6,100	6,100
Upper Mitta Mitta River	47,500	0	19,300	19,300
TOTAL	**766,800**	**12,700**	**141,000**	**128,300**

Figure 4. Catchment boundaries and land use in the Upper Murray River Basin

4. Impacts on water yield

The greatest impacts from reforestation, in terms of ML per hectare reductions in water yield, were in the lower and middle Mitta Mitta River catchments, with reductions under average rainfall conditions of 1.2 to 1.3 ML per hectare (Table 3). Under dry conditions, the greatest impacts were in the Cobungra River and Big River catchments with yield reductions of 0.7 to 1.0 ML per hectare. Under wet conditions, the greatest impacts were in the Lower Mitta Mitta River and Corryong Creek catchments with yield reductions of around 1.5 ML per hectare.

The catchment where reforestation would potentially cause the largest reduction in water yield was not surprisingly the smallest catchment, Maragle Creek. The total land area suitable for reforestation, as defined in this study (i.e. pasture land not under National Park) in the Maragle Creek catchment was estimated at around 8,000 ha. Reforestation on this scale in this locality is highly unlikely. However, if it occurred, it would potentially reduce runoff in the Maragle Creek catchment by between 9% and 33%, depending on rainfall conditions. While these are only very small amounts of water (3 – 11.5 giga-litres [GL]) compared with average total runoff in the Upper Murray River basin (~4,000 GL), they may still represent a significant local impact in a small catchment.

Impacts in individual catchments

The results of the analyses are described below for each catchment and summarised in Table 3.

Tumbarumba Creek

Land cover in the Tumbarumba Creek catchment in the north of the Upper Murray River Basin is dominated by open forest. There are also around 3,400 ha of existing plantation forest and around 6,700 ha of pasture land, mostly in the south and central-west of the catchment (Figure 5). None of the catchment is within National Park.

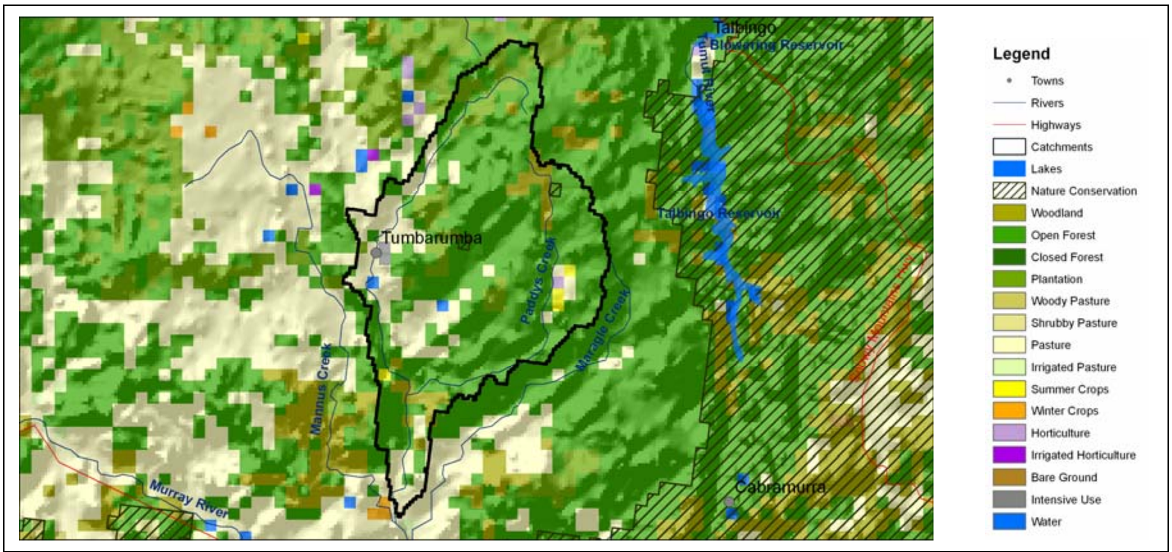

Figure 5. Land use in the Tumbarumba Creek catchment

The water balance model estimated the catchment yield to be approximately 109 GL on average. Conversion of all pasture land to plantation forest would increase the plantation forest estate from 3,400 ha to 10,100 ha (300%). This change reduced the yield of the catchment by around 7 GL, or about 6.5% of the total catchment yield under average rainfall conditions.

The water balance model estimated the catchment yield to be approximately 26 GL in a "dry" year (two-thirds average rainfall). Conversion of all pasture land to plantation forest reduced the yield of the catchment by around 3.5 GL, or about 13% of the total catchment yield under "dry" conditions.

The water balance model estimated the catchment yield to be approximately 311 GL in a "wet" year (one-and-a-half times the average rainfall). Conversion of all pasture land to plantation forest reduced the yield of the catchment by around 9.5 GL, or about 3% of the total catchment yield under "wet" conditions.

Maragle Creek

Land cover in the Maragle Creek catchment in the northeast of the Upper Murray River Basin is dominated by open forest and pasture. The pasture land, around 8,300 ha, lies mostly in the southwest and centre of the catchment. There are also around 1,000 ha of existing plantation forest (Figure 6). None of the catchment is within National Park.

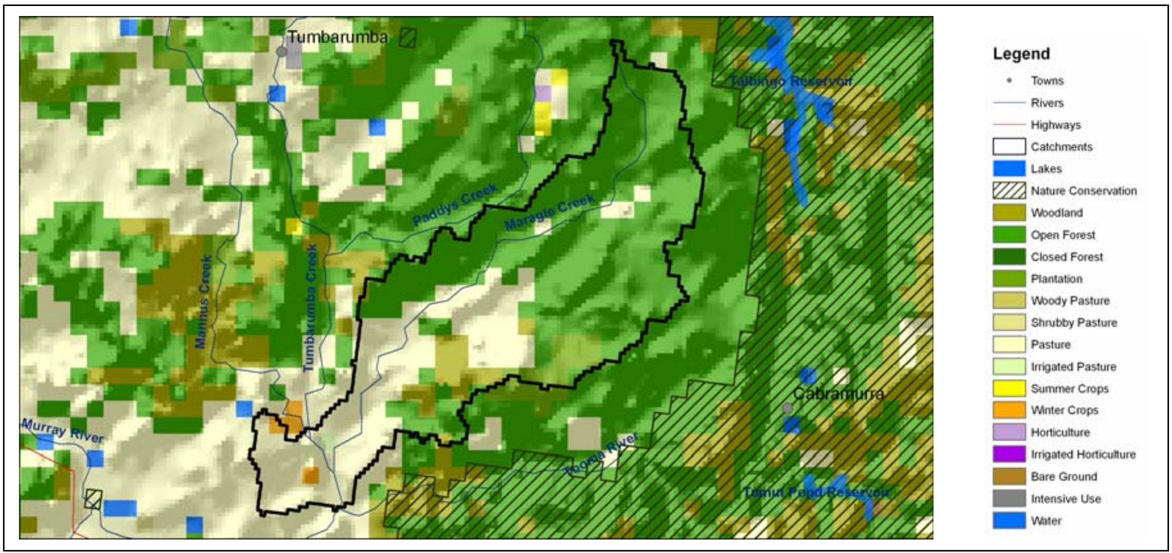

Figure 6. Land use in the Maragle Creek catchment

The water balance model estimated the catchment yield to be approximately 41 GL on average. Conversion of all pasture land to plantation forest would increase the plantation forest estate from 1,000 ha to 9,300 ha (930%). This change reduced the yield of the catchment by around 7 GL, or about 17% of the total catchment yield under average rainfall conditions.

The water balance model estimated the catchment yield to be approximately 9 GL in a "dry" year (two-thirds average rainfall). Conversion of all pasture land to plantation forest reduced the yield of the catchment by around 3 GL, or about 32% of the total catchment yield under "dry" conditions.

The water balance model estimated the catchment yield to be approximately 130 GL in a "wet" year (one-and-a-half times the average rainfall). Conversion of all pasture land to plantation forest reduced the yield of the catchment by around 11.5 GL, or about 9% of the total catchment yield under "wet" conditions.

Tooma River

Land cover in the Tooma River catchment in the northeast of the Upper Murray River Basin is dominated by open forest and woodland. There are also around 600 ha of existing plantation forest and around 1,500 ha of pasture land in the north of the catchment (Figure 7). Most of the catchment is within National Park, except for a small section along the catchment's northern boundary.

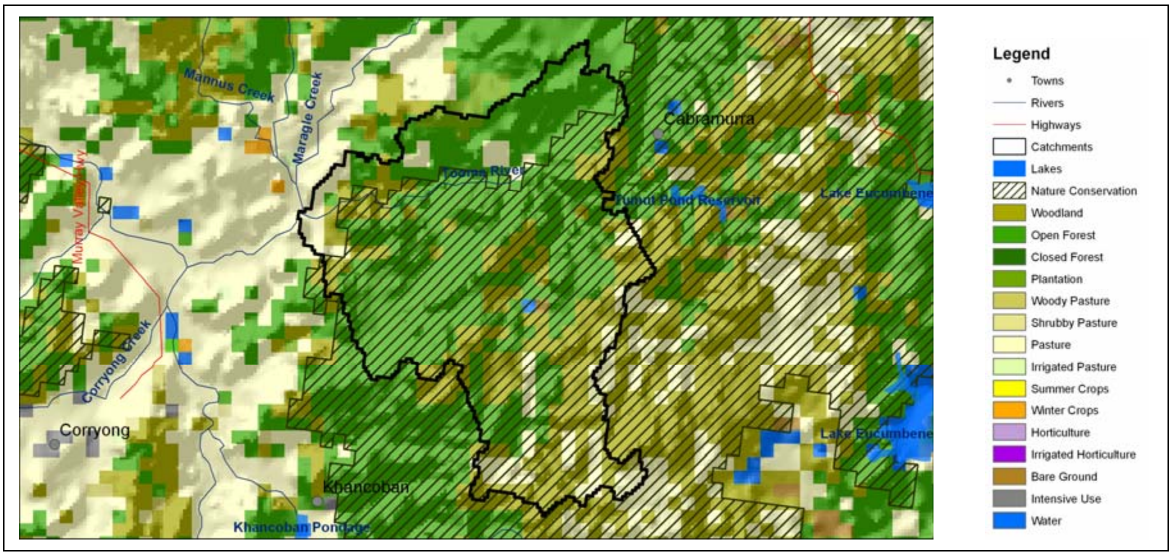

Figure 7. Land use in the Tooma River catchment

The water balance model estimated the catchment yield to be approximately 236 GL on average. Conversion of all pasture land not within National Park to plantation forest increased the plantation forest estate from 600 ha to 2,100 ha (350%). This change reduced the yield of the catchment by around 1.5 GL, or about 0.6% of the total catchment yield under average rainfall conditions.

The water balance model estimated the catchment yield to be approximately 84 GL in a "dry" year (two-thirds average rainfall). Conversion of pasture land to plantation forest would reduce the yield of the catchment by around 0.5 GL, or about 0.7% of the total catchment yield under "dry" conditions.

The water balance model estimated the catchment yield to be approximately 537 GL in a "wet" year (one-and-a-half times the average rainfall). Conversion of pasture land to plantation forest would reduce the yield of the catchment by around 2 GL, or about 0.4% of the total catchment yield under "wet" conditions.

Cudgewa Creek

Land cover in the Cudgewa Creek catchment in the centre-north of the Upper Murray River Basin is dominated by open forest, woodland and pasture. The pasture land, around 20,900 ha, lies mostly in the centre and northeast of the catchment. There are also around 6,400 ha of existing plantation forest (Figure 8). About a third of the catchment is within National Park, mostly in two discrete areas in the south and north.

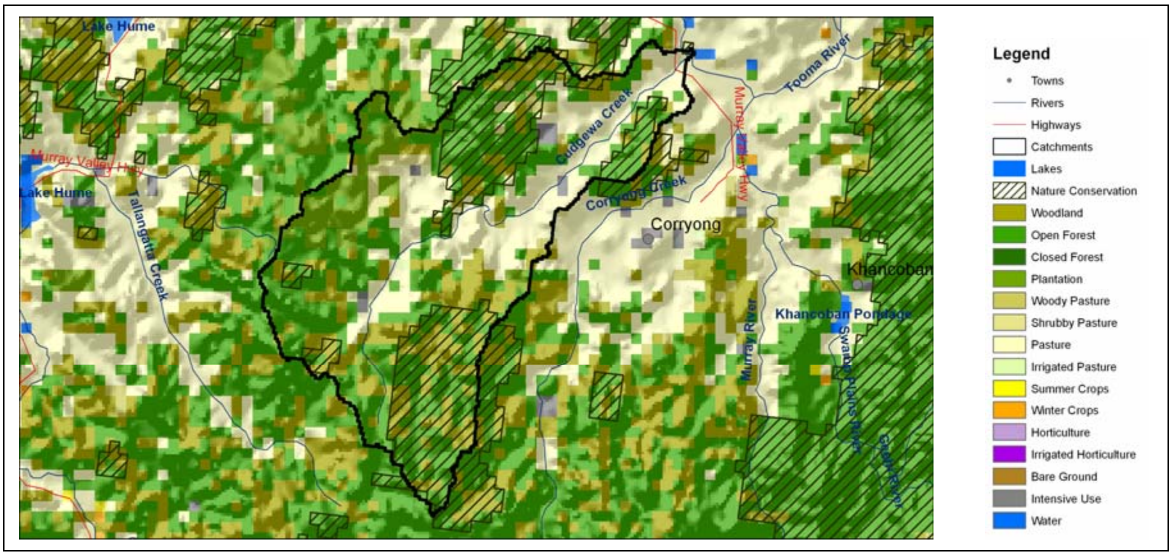

Figure 8. Land use in the Cudgewa Creek catchment

The water balance model estimated the catchment yield to be approximately 170 GL on average. Conversion of all pasture land not under National Park to plantation forest increased the plantation forest estate from 6,400 ha to 27,300 ha (430%). This change would reduce the yield of the catchment by around 22 GL, or about 13% of the total catchment yield under average rainfall conditions.

The water balance model estimated the catchment yield to be approximately 42 GL in a "dry" year (two-thirds average rainfall). Conversion of pasture land to plantation forest would reduce the yield of the catchment by around 10 GL, or about 24% of the total catchment yield under "dry" conditions.

The water balance model estimated the catchment yield to be approximately 501 GL in a "wet" year (one-and-a-half times the average rainfall). Conversion of pasture land to plantation forest would reduce the yield of the catchment by around 30 GL, or about 6% of the total catchment yield under "wet" conditions.

Corryong Creek

Land cover in the Corryong Creek catchment in the centre of the Upper Murray River Basin is dominated by open forest and woodland. There are also around 100 ha of existing plantation forest and around 20,100 ha of pasture land, mostly in the north of the catchment (Figure 9). Small parts of the south, west, centre and north of the catchment is within National Park.

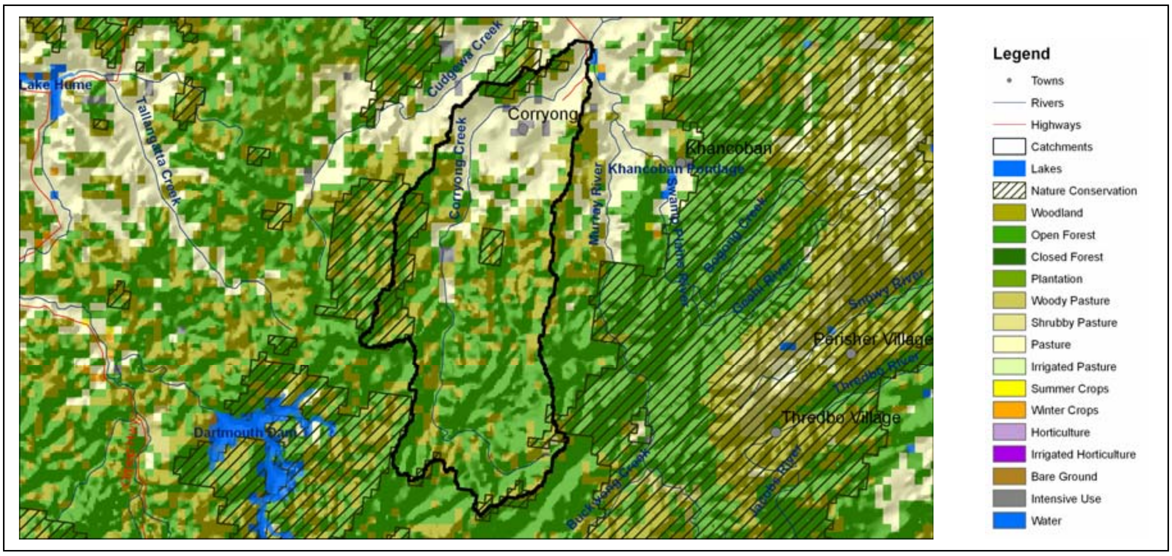

Figure 9. Land use in the Corryong Creek catchment

The water balance model estimated the catchment yield to be approximately 310 GL on average. Conversion of all pasture land not under National Park to plantation forest would increase the plantation forest estate from 100 ha to 20,200 ha (200 fold). This change would reduce the yield of the catchment by around 19.5 GL, or about 6.5% of the total catchment yield under average rainfall conditions.

The water balance model estimated the catchment yield to be approximately 93 GL in a “dry” year (two-thirds average rainfall). Conversion of pasture land to plantation forest would reduce the yield of the catchment by around 8 GL, or about 9% of the total catchment yield under “dry” conditions.

The water balance model estimated the catchment yield to be approximately 782 GL in a “wet” year (one-and-a-half times the average rainfall). Conversion of pasture land to plantation forest would reduce the yield of the catchment by around 29.5 GL, or about 4% of the total catchment yield under “wet” conditions.

Lower Mitta Mitta River

Land cover in the Lower Mitta Mitta River catchment in the central-west of the Upper Murray River Basin is dominated by open forest and woodland. There are also around 1,000 ha of existing plantation forest and around 21,700 ha of pasture land, mostly in the north of the catchment (Figure 10). A very small patch on the eastern boundary of the catchment is within National Park.

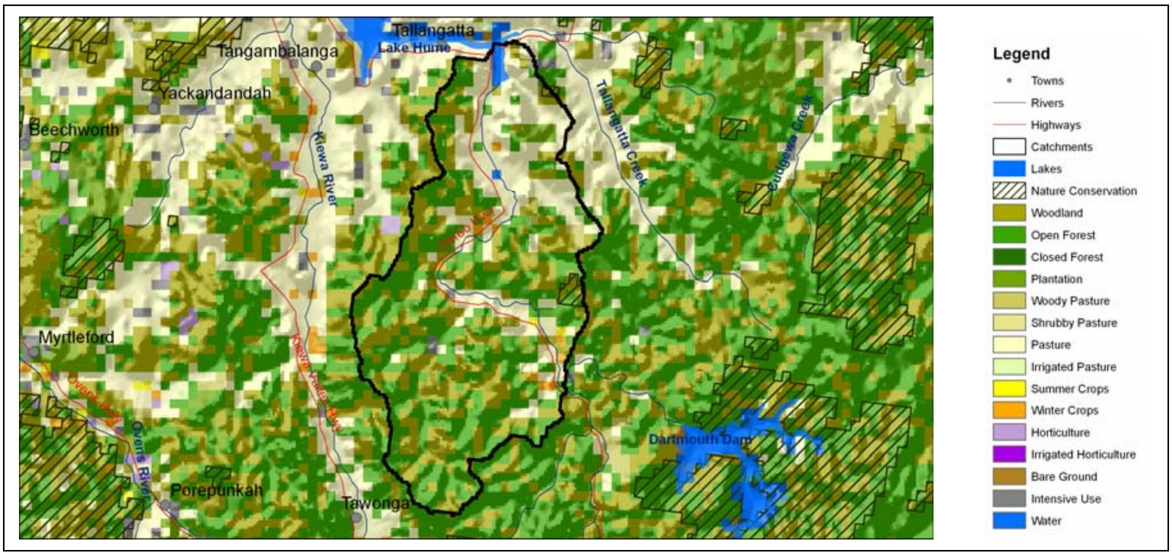

Figure 10. Land use in the Lower Mitta Mitta River catchment

The water balance model estimated the catchment yield to be approximately 215 GL on average. Conversion of all pasture land not under National Park to plantation forest would increase the plantation forest estate from 1,000 ha to 22,700 ha (20 fold). This change would reduce the yield of the catchment by around 25.5 GL, or about 12% of the total catchment yield under average rainfall conditions.

The water balance model estimated the catchment yield to be approximately 59 GL in a “dry” year (two-thirds average rainfall). Conversion of pasture land to plantation forest would reduce the yield of the catchment by around 12.5 GL, or about 21% of the total catchment yield under “dry” conditions.

The water balance model estimated the catchment yield to be approximately 587 GL in a “wet” year (one-and-a-half times the average rainfall). Conversion of pasture land to plantation forest would reduce the yield of the catchment by around 32 GL, or about 5.5% of the total catchment yield under “wet” conditions.

Middle Mitta Mitta River

Land cover in the Middle Mitta Mitta River catchment in the centre of the Upper Murray River Basin is dominated by open forest and woodland. There are also around 200 ha of existing plantation forest and around 800 ha of pasture land in the northwest of the catchment (Figure 11). About half of the catchment is within National Park, mostly in the centre and south.

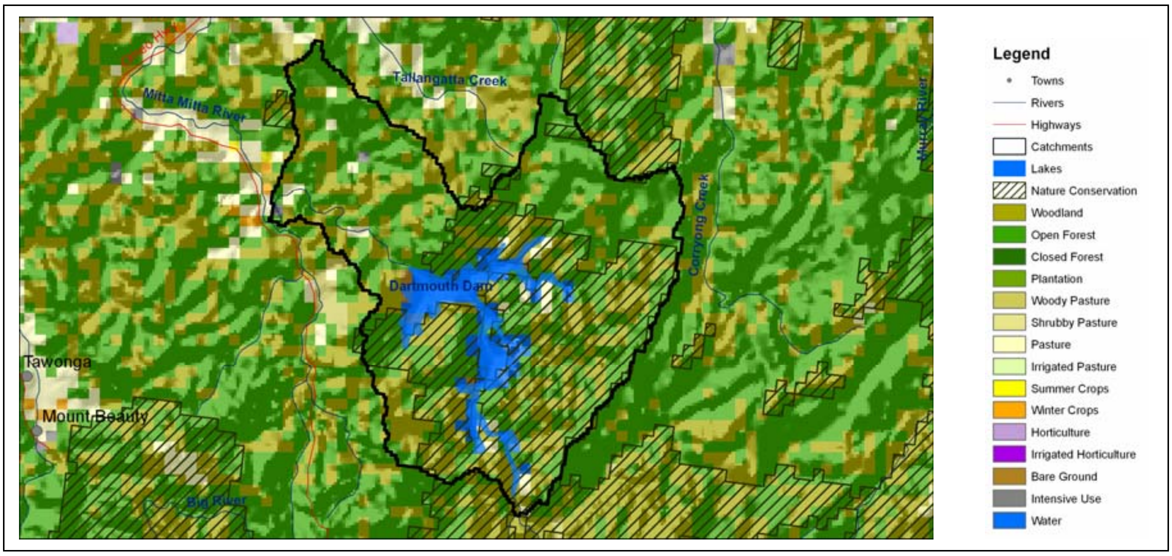

Figure 11. Land use in the Middle Mitta Mitta River catchment

The water balance model estimated the catchment yield to be approximately 305 GL on average. Conversion of all pasture land not under National Park to plantation forest would increase the plantation forest estate from 200 ha to 1000 ha (500%). This change would reduce the yield of the catchment by around 1 GL, or about 0.5% of the total catchment yield under average rainfall conditions.

The water balance model estimated the catchment yield to be approximately 88 GL in a “dry” year (two-thirds average rainfall). Conversion of pasture land to plantation forest would reduce the yield of the catchment by around 0.5 GL, or about 0.5% of the total catchment yield under “dry” conditions.

The water balance model estimated the catchment yield to be approximately 781 GL in a “wet” year (one-and-a-half times the average rainfall). Conversion of pasture land to plantation forest would reduce the yield of the catchment by around 1 GL, or about 0.1% of the total catchment yield under “wet” conditions.

Snowy Creek

Land cover in the Snowy Creek catchment in the central-west of the Upper Murray River Basin is dominated by open forest and woodland. There is no existing plantation forest and around 1,800 ha of pasture land in the north of the catchment (Figure 12). A small section of the catchment in the southwest is within National Park.

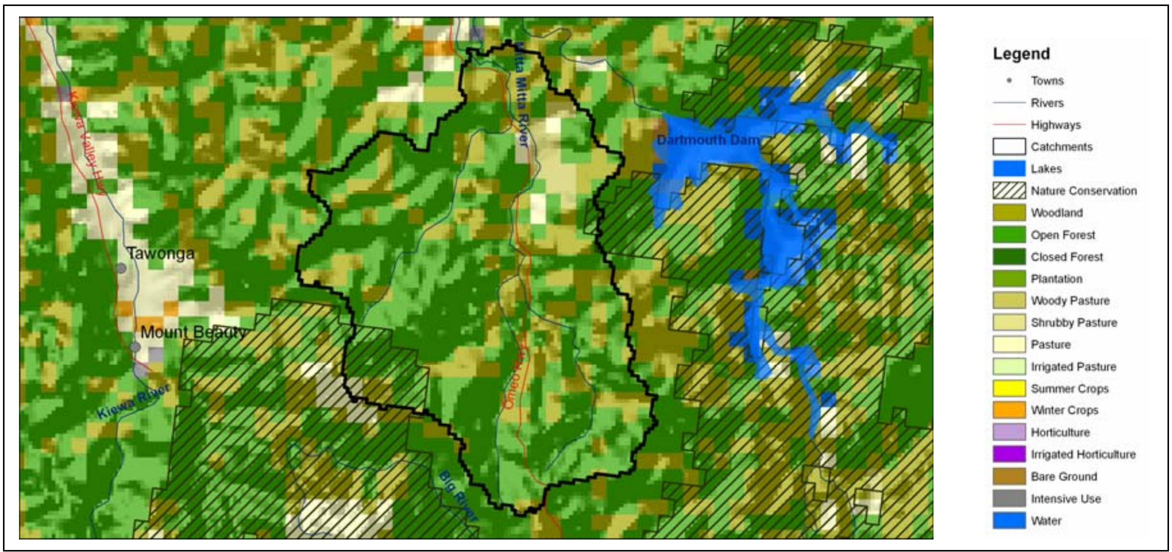

Figure 12. Land use in the Snowy Creek catchment

The water balance model estimated the catchment yield to be approximately 219 GL on average. Conversion of all pasture land not under National Park to plantation forest would increase the plantation forest estate from 0 ha to 1,800 ha. This change would reduce the yield of the catchment by around 2 GL, or about 1% of the total catchment yield under average rainfall conditions.

The water balance model estimated the catchment yield to be approximately 72 GL in a "dry" year (two-thirds average rainfall). Conversion of pasture land to plantation forest would reduce the yield of the catchment by around 1 GL, or about 1.5% of the total catchment yield under "dry" conditions.

The water balance model estimated the catchment yield to be approximately 511 GL in a "wet" year (one-and-a-half times the average rainfall). Conversion of pasture land to plantation forest would reduce the yield of the catchment by around 2 GL, or about 0.5% of the total catchment yield under "wet" conditions.

Morass River

Land cover in the Morass River catchment in the southeast of the Upper Murray River Basin is dominated by open forest and woodland. There is no existing plantation forest and around 19,500 ha of pasture land, mostly in the southwest of the catchment (Figure 13). About 20% of the catchment is within National Park, mostly in a band running through the centre of the catchment and a small patch also in the southeast.

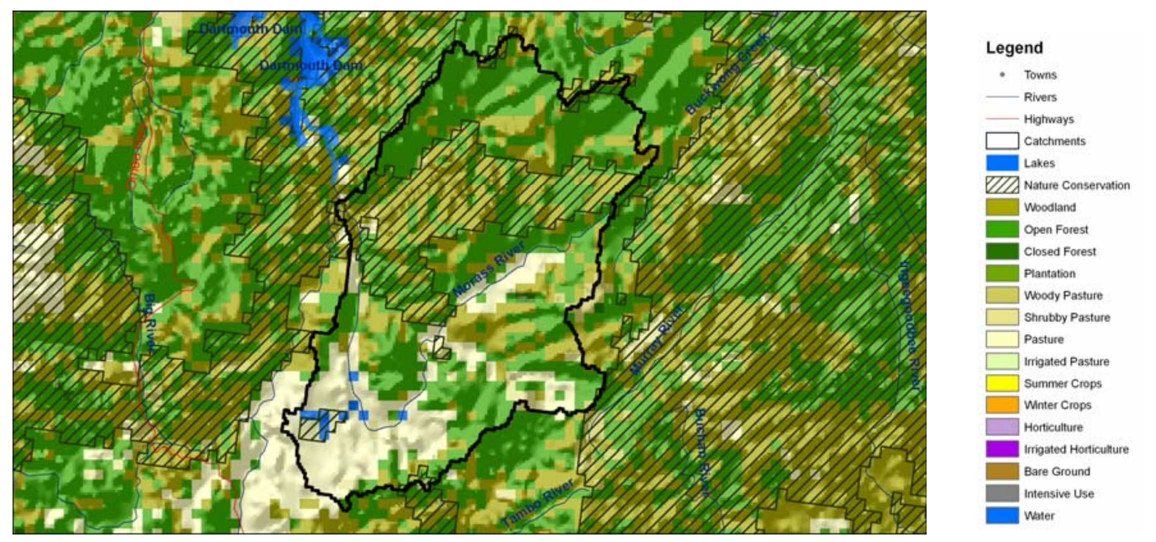

Figure 13. Land use in the Morass River catchment

The water balance model estimated the catchment yield to be approximately 307 GL on average. Conversion of all pasture land not under National Park to plantation forest increased the plantation forest estate from 0 ha to 19,500 ha. This change would reduce the yield of the catchment by around 16.5 GL, or about 5.5% of the total catchment yield under average rainfall conditions.

The water balance model estimated the catchment yield to be approximately 93 GL in a “dry” year (two-thirds average rainfall). Conversion of pasture land to plantation forest would reduce the yield of the catchment by around 8 GL, or about 9% of the total catchment yield under “dry” conditions.

The water balance model estimated the catchment yield to be approximately 777 GL in a “wet” year (one-and-a-half times the average rainfall). Conversion of pasture land to plantation forest would reduce the yield of the catchment by around 22 GL, or about 3% of the total catchment yield under “wet” conditions.

Big River

Land cover in the Big River catchment in the southwest of the Upper Murray River Basin is dominated by open forest and woodland. There is no existing plantation forest and around 1,600 ha of pasture land, mostly in the south of the catchment (Figure 14). Most of the west and south of the catchment is within National Park, covering around two-thirds of the total area.

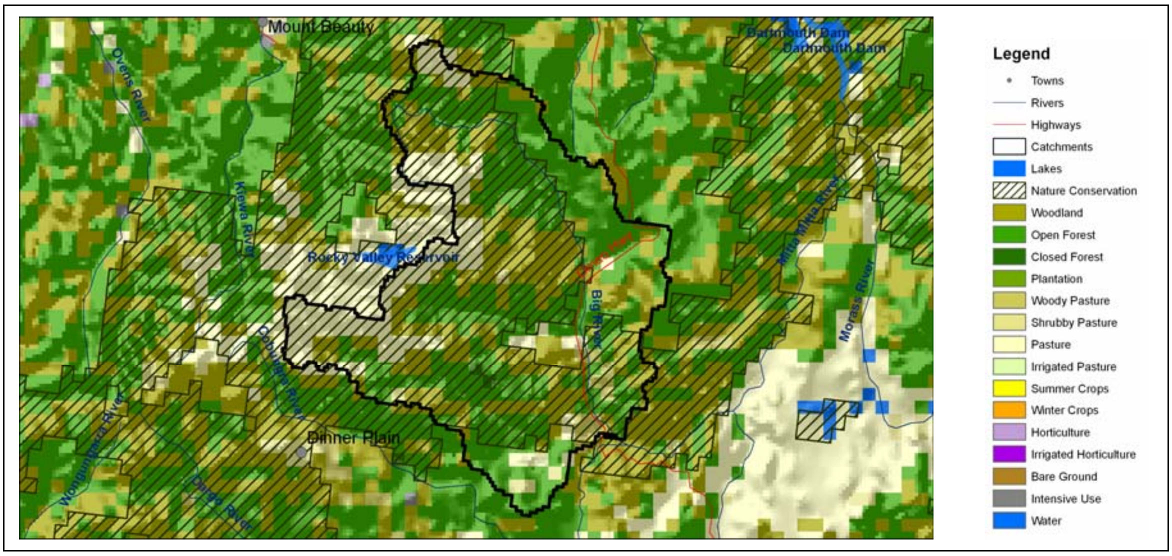

Figure 14. Land use in the Big River catchment

The water balance model estimated the catchment yield to be approximately 361 GL on average. Conversion of all pasture land not under National Park to plantation forest increased the plantation forest estate from 0 ha to 1,600 ha. This change would reduce the yield of the catchment by around 1.5 GL, or about 0.5% of the total catchment yield under average rainfall conditions.

The water balance model estimated the catchment yield to be approximately 149 GL in a "dry" year (two-thirds average rainfall). Conversion of pasture land to plantation forest would reduce the yield of the catchment by around 1 GL, or about 0.5% of the total catchment yield under "dry" conditions.

The water balance model estimated the catchment yield to be approximately 738 GL in a "wet" year (one-and-a-half times the average rainfall). Conversion of pasture land to plantation forest would reduce the yield of the catchment by around 1.5 GL, or about 0.2% of the total catchment yield under "wet" conditions.

Cobungra River

Land cover in the Cobungra River catchment in the southwest of the Upper Murray River Basin is dominated by open forest and woodland. There is no existing plantation forest and around 6,100 ha of pasture land, mostly in the southeast of the catchment (Figure 15). About 20% of the catchment in the northwest is within National Park.

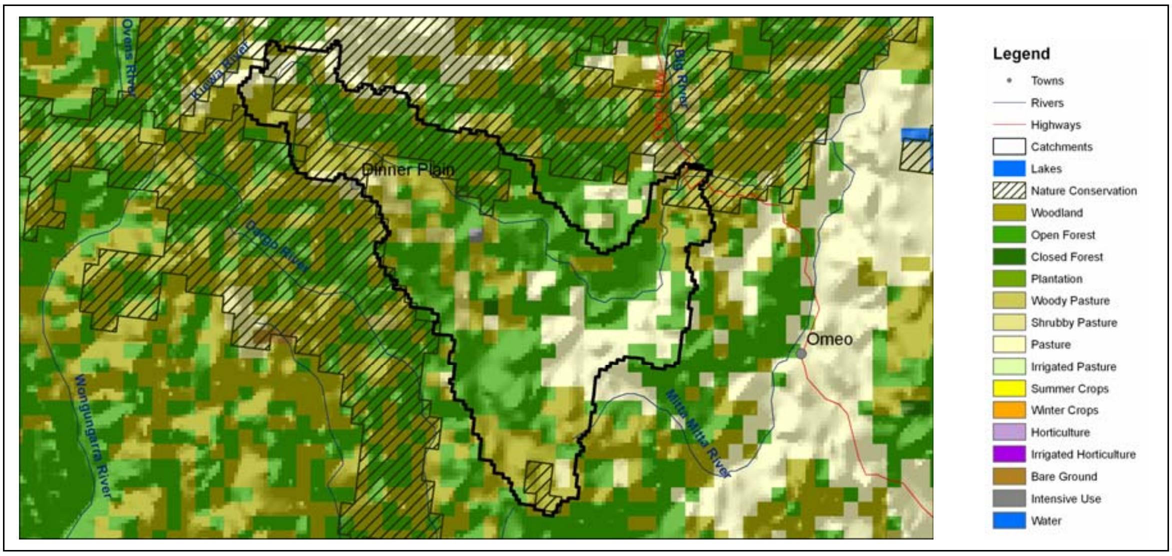

Figure 15. Land use in the Cobungra River catchment

The water balance model estimated the catchment yield to be approximately 304 GL on average. Conversion of all pasture land not under National Park to plantation forest increased the plantation forest estate from 0 ha to 6,100 ha. This change would reduce the yield of the catchment by around 6 GL, or about 2% of the total catchment yield under average rainfall conditions.

The water balance model estimated the catchment yield to be approximately 123 GL in a “dry” year (two-thirds average rainfall). Conversion of pasture land to plantation forest would reduce the yield of the catchment by around 6 GL, or about 5% of the total catchment yield under “dry” conditions.

The water balance model estimated the catchment yield to be approximately 619 GL in a “wet” year (one-and-a-half times the average rainfall). Conversion of pasture land to plantation forest would reduce the yield of the catchment by around 4 GL, or about 0.5% of the total catchment yield under “wet” conditions.

Upper Mitta Mitta River

Land cover in the Upper Mitta Mitta River catchment in the south of the Upper Murray River Basin is dominated by open forest and pasture. The pasture land, around 19,300 ha, lies mostly in the centre and north of the catchment. There is no existing plantation forest (Figure 16). There is a small patch of National Park in the south of the catchment.

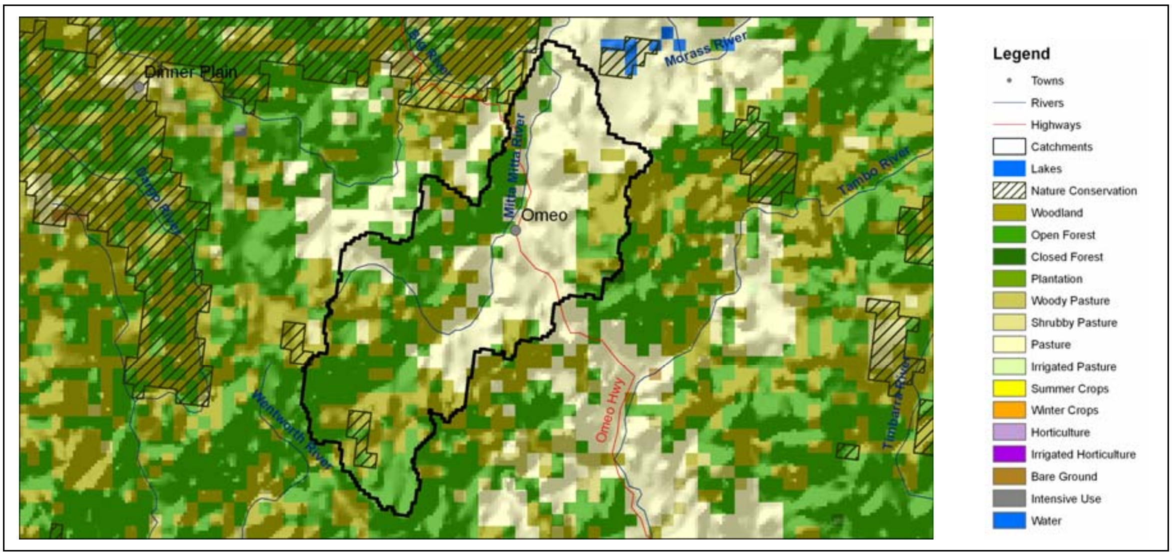

Figure 16. Land use in the Upper Mitta Mitta River catchment

The water balance model estimated the catchment yield to be approximately 116 GL on average. Conversion of all pasture land not under National Park to plantation forest increased the plantation forest estate from 0 ha to 19,300 ha. This change would reduce the yield of the catchment by around 16 GL, or about 13.5% of the total catchment yield under average rainfall conditions.

The water balance model estimated the catchment yield to be approximately 35 GL in a “dry” year (two-thirds average rainfall). Conversion of pasture land to plantation forest would reduce the yield of the catchment by around 8 GL, or about 22% of the total catchment yield under “dry” conditions.

The water balance model estimated the catchment yield to be approximately 298 GL in a “wet” year (one-and-a-half times the average rainfall). Conversion of pasture land to plantation forest would reduce the yield of the catchment by around 23 GL, or about 7.5% of the total catchment yield under “wet” conditions.

Table 3. Impact on water yield in individual catchments from reforestation of all available pasture land (i.e., not under National Park)

Catchment Description	Annual yield (GL)	Annual yield after reforestation (GL)	Difference (GL)	% Yield reduction	ML/ha yield reduction*
Average annual rainfall scenario					
Tumbarumba Creek	109.3	102.4	-6.9	-6.3	-1.03
Maragle Creek	41.5	34.4	-7.1	-17.1	-0.85
Tooma River	235.7	234.4	-1.4	-0.6	-0.91
Cudgewa Creek	170.4	148.2	-22.2	-13.0	-1.06
Corryong Creek	309.6	289.9	-19.7	-6.4	-0.98
Lower Mitta Mitta River	215.1	189.6	-25.5	-11.8	-1.17
Middle Mitta Mitta River	304.7	303.7	-1.0	-0.3	-1.28
Snowy Creek	219.2	217.3	-1.9	-0.9	-1.06
Morass River	307.0	290.7	-16.3	-5.3	-0.83
Big River	360.9	359.2	-1.7	-0.5	-1.06
Cobungra River	304.2	298.3	-5.9	-1.9	-0.97
Upper Mitta Mitta River	116.5	100.6	-15.9	-13.6	-0.82
TOTAL	**2694.3**	**2568.9**	**-125.4**	**-4.7**	**-1.00**
Dry year scenario					
Tumbarumba Creek	25.7	22.4	-3.3	-13.0	-0.50
Maragle Creek	9.0	6.2	-2.8	-31.5	-0.34
Tooma River	84.3	83.7	-0.6	-0.7	-0.37
Cudgewa Creek	41.8	31.8	-10.0	-23.9	-0.48
Corryong Creek	93.2	85.0	-8.2	-8.8	-0.41
Lower Mitta Mitta River	59.5	47.1	-12.4	-20.8	-0.57
Middle Mitta Mitta River	88.0	87.5	-0.5	-0.6	-0.65
Snowy Creek	71.8	70.9	-1.0	-1.4	-0.55
Morass River	92.8	84.6	-8.2	-8.8	-0.42
Big River	149.0	147.9	-1.1	-0.7	-0.66
Cobungra River	123.3	117.3	-6.0	-4.9	-0.98
Upper Mitta Mitta River	35.2	27.4	-7.8	-22.1	-0.40
TOTAL	**873.7**	**811.9**	**-61.8**	**-7.1**	**-0.53**
Wet year scenario					
Tumbarumba Creek	311.2	301.8	-9.4	-3.0	-1.40
Maragle Creek	130.5	119.1	-11.4	-8.7	-1.37
Tooma River	537.3	535.2	-2.1	-0.4	-1.41
Cudgewa Creek	501.2	471.1	-30.2	-6.0	-1.44
Corryong Creek	782.4	752.9	-29.5	-3.8	-1.47
Lower Mitta Mitta River	586.7	554.6	-32.1	-5.5	-1.48
Middle Mitta Mitta River	780.7	779.6	-1.2	-0.1	-1.45
Snowy Creek	510.5	508.6	-2.0	-0.4	-1.09
Morass River	776.6	754.6	-22.0	-2.8	-1.13
Big River	737.7	736.0	-1.6	-0.2	-1.01
Cobungra River	619.1	615.2	-3.9	-0.6	-0.65
Upper Mitta Mitta River	297.8	274.8	-22.9	-7.7	-1.19
TOTAL	**6571.7**	**6403.5**	**-168.1**	**-2.6**	**-1.26**

* refers to per hectare of new plantation forest

5. Discussion

Study assumptions and limitations

The water balance model used in this investigation is a steady-state (long-term average) model that assumes relatively stable, mature vegetation cover. It may not accurately reflect 'transitional' effects, where reforestation is gradual or where streamflow is still responding to past events. The model uses a relatively simple spatial dataset to describe forest structure. Actual forest structure may vary in significantly more complex fashions within and between catchments.

The work of Zhang *et al*. (2003), described in Figure 2, suggests that water yield in mature plantation forests is around 100 to 150 mm/year (1 – 1.5 ML/ha) less than on pasture land under the same climatic conditions. However, when agricultural land is reforested, yield reductions are minor for the first five years and increase to a peak 10–20 years after planting (Zhang *et al*. 2006). This cycle starts again when the plantation is harvested and replanted. The usual thinning applied in pine plantations increases streamflow for several years (Bren *et al*. 2006). About 57% of Australia's plantations are pines that are typically thinned two or three times during a production cycle of 30 or more years. Eucalypt plantations are typically grown on a cycle of 10 to 15 years and some of these are also thinned.

Due to these fluctuations in water use during the production cycle, only a proportion of a plantation estate will be at peak water use at any given time. The impact of commercial plantation forest estates on run-off will therefore be less on average than indicated in Figure 2. Average water use during a typical pine plantation production cycle use has been estimated to be around 70% of peak water use (Pratt Water 2004b). This described effect has not been factored into the analyses or outcomes presented in this paper.

Forecast plantation expansion in the Upper Murray River Basin

The total plantation area in the Murray-Darling Basin in 2005 is estimated to be 284,000 hectares (source: National Plantation Inventory). A few thousand hectares per year of new radiata pine plantations and a few hundred hectares of hardwood plantations have been established in the uplands of the Basin over the past five to ten years. These increases have been substantially offset by reductions due to land use change and re-measurements of previously established areas such that the total area under plantation has changed little.

The plantation industry's reported expansion target for the upper Murray-Darling Basin is currently less than 50,000 hectares of new softwood plantations by 2020. If, where and when that expansion occurs depends on availability of suitable land at prices considered economic for plantation forestry, availability of investment funds and other factors.

Impact of forecast plantation expansion on water yield

For the following analysis, it was assumed that up to 30,000 hectares of the anticipated 50,000 hectares of new plantation in the Murray-Darling Basin would be established in the catchments of the Upper Murray River Basin studied in this report and described in Table 2.

With respect to such a 30,000 ha expansion, the minimum impact scenario described in Table 4 was calculated by 'planting' as much new forest as possible in the catchment with the lowest estimated ML/ha reduction in water yield from Table 3, and then subsequently planting as much new forest as possible in the catchment with the second lowest estimated ML/ha reduction in water yield, and so on until 30,000 ha of forest had been established.

The maximum impact scenario in Table 4 was calculated by ‘planting’ as much new forest as possible in the catchment with the highest estimated ML/ha reduction in water yield from Table 3, and then subsequently planting as much new forest as possible in the catchment with the second highest estimated ML/ha reduction in water yield, and so on until 30,000 ha of forest had been established.

The analysis showed that the forecast 30,000 ha increase in plantation forests – from 12,700 ha to 42,700 ha – would reduce water yield by 25 to 35 GL/year depending on the location of the additional plantations, under average rainfall conditions (Table 4). This represented approximately 0.9% to 1.3% of total modelled annual yield, and equates to a reduction in yield of around 1.0 ML per hectare on the land converted from pasture to forest.

In low rainfall years, the forecast new plantations were estimated to reduce yield by 12 to 17 GL/year (1.4% to 1.9% of modelled annual yield) as shown in Table 4. In high rainfall years, the forecast new plantations were estimated to reduce yield by 35 to 44 GL/year (0.5% to 0.7% of modelled annual yield).

Table 4. Impacts of forecast plantation expansion of 30,000 ha in selected catchments of the Upper Murray River Basin

Scenario	Annual yield (GL)	Minimum impact (GL/year)	Proportion	Maximum impact (GL/year)	Proportion
Dry year	874	-12	-1.4%	-17	-1.9%
Average rainfall	2694	-25	-0.9%	-35	-1.3%
Wet year	6572	-35	-0.5%	-44	-0.7%

6. Acknowledgments

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7. References

Best, A., Davidson, A. J., Podger, G. M., Dowling T. I. and Zhang L. (in press). Linking land use change and river systems models for the Murrumbidgee Basin, Australia. Murray-Darling Basin Commission.

Bren, L. J., Land, P. and McGuire, D. 2006. An empirical, comparative model of changes in annual water yield associated with pine plantations in southern Australia. Australian Forestry vol. 69, pp. 275-284.Fu, B.P. (1981) On the calculation of the evaporation from land surface (in Chinese). Scientia Atmospherica Sinica 5, 23-31.

Pratt Water 2004b. Plantations Feasibility Project. Pratt Water, Campbellfield.

Raupach, M.R., Kirby, J.M., Barrett, D.J., Briggs, H. Lu, H. and Zhang, L. (2001) Balances of water, carbon, nitrogen and phosphorus in Australian Landscapes: (2) Model formulation and testing. Technical Report 41/01, CSIRO Land and Water.

Zhang, L., T. Dowling, M. Hocking, J. Morris, G. Adams, K. Hickel, A. Best and R. Vertessy 2003. Predicting the effects of large-scale afforestation on annual flow regime and water allocation. CRC for Catchment Hydrology Technical Report 03/5.

Zhang, L., Hickel, K., Dawes, W.R., Chiew, F.H.S., Western, A.W. and Briggs, P.R. (2004) A rational function approach for estimating mean annual evaporation. Water Resources Research, 40.

Zhang, L., Hickel, K. and Shao, Q. (in press) Water balance modelling over variable time scales. MODSIM Conference, December 2005, Melbourne.