# Resource Conflict Across Melbourne's Largest Domestic Water Supply Catchment

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*Previous page: Clearfell logging in the Thomson Catchment with the Thomson Reservoir in the background (Photo: C. Taylor)*

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## Abstract

Quantifying the effects of competition for natural resources between different sectors and interests is a key part of natural resource management globally. A major form of land use conflict in natural forests is between water production and timber production. Here we explore trade-offs in water yield resulting from logging in the forested water catchments north-east of Melbourne – the second largest urban settlement in Australia with a current population of five million. It has long been understood that logging significantly decreases water yields in Melbourne's water catchments. However, the extent of losses of water yield from past logging have rarely been documented. Here, we model changes in water yield in Melbourne's largest single catchment, the Thomson Catchment, resulting from: **(1)** past forest management activities (especially clearfell logging), and **(2)** future forest management scenarios. Our particular focus was on the effects of logging on water yields from ash-type eucalypt forests. This is because these areas have the greatest impact on water runoff due to them receiving the most rainfall and being the forest types subject to the most intensive and extensive industrial logging. We modelled four key scenarios:

- **Scenario (1)** Historical logging of the Thomson Catchment with continued logging in the future (current reality/status quo);
- **Scenario (2)** If there had been no logging and none was planned (past, present or future) in the Thomson Catchment;
- **Scenario (3)** Logging ceasing in 1967 (as specified under the first *Wood Pulp Agreement Act 1936* – but which never occurred); and
- **Scenario (4)** Impacts of the past logging, but with cessation of logging in 2018.

Our initial spatial analysis revealed that 42% of the ash-type eucalypt forests in the Thomson Catchment have been logged. Moreover, there are 4,000 hectares of Ash forest assigned for logging in the next 5 years under the existing Timber Release Plan for the Central Highlands region. Our analyses revealed that the current (in 2018) reduction in water yield due to historical logging of the ash forests across the Thomson Catchment exceeds 15,000 ML annually. This loss is projected to increase to nearly 35,156 ML by 2050. Under Scenario (3), where logging would have ceased in 1967 if the first Wood Pulp Agreement 1936 was implemented, the loss in water yield by 2018 was projected to be 1,079 ML, annually. This loss is a result of logging occurring prior to 1967. This was modelled to remain constant through to 2050. Under Scenario (4), where logging ceases in 2018, we projected that approximately 20,149 ML would have been returned to the Thomson Catchment by 2050 compared with Scenario (2) of no historical logging. Losses in water yield as a result of logging correspond to 9%-20% of the ash forest catchment water yield for 2018 and 2050, respectively. Based on an estimated consumption of 161 litres of water per person per day, the loss in water yield resulting from logging would equate to the lost water for nearly 600,000 people by 2050.

Given the strategic importance of water from the Thomson Catchment, our analyses suggest that native forest logging should be excluded from this catchment, particularly in the context of increasing human consumption of water and decreasing stream inflows from the catchments. Previous work has shown that the economic value of the water across all of Melbourne's Water Catchments, including the Thomson Catchment, is 25.5 times greater than the economic value of the timber produced from the all native forests, based on integrated economic and environmental accounting (e.g. under the System of Environmental and Economic Accounting [SEEA] developed by the United Nations). It is not the difference in value between water and timber that is important, it is the change due to the use of an ecosystem service, resulting in the reduction of water yield. Therefore, we suggest that ongoing logging of the Thomson Catchment, when it is known to reduce water yields, is a questionable natural resource management policy.

## Introduction

Global extraction of natural resources and materials, such as minerals, agriculture and fossil fuels, has increased significantly from 22 billion tonnes in 1970 to 70 billion tonnes in 2010 *[1]*. Escalating demand may jeopardise access to some essential resources, create conflict among various uses of ecosystem services and cause environmental harm *[2]*. As consumption increases, countries will face growing shortages of vital renewable resources such as freshwater, forests and wildlife *[3]*. In all of these cases, institutional, political or economic factors can be as important as environmental factors in limiting the availability of natural resources. Governments can exacerbate resource scarcity, particularly through perverse subsidies or poor policies *[4]*.

At a global scale, human demand for land is increasing, highlighting a need for more efficient land use allocation and innovation *[5]*. How land is used is influenced by a range of factors, such as climate, population, government policy, market forces, technology, affluence and societal preferences. These factors will change rapidly over the next few decades, potentially transforming the use and management of land *[6]*. Competing land uses often generate conflict in the use of ecosystem services between different sectors, where resources extracted by one land use can impact on the ability to obtain a different resource *[7]*. Landscape approaches and a sound understanding of impacts to resource availability are needed for allocating and managing land to achieve social, economic, and environmental objectives in areas where agriculture and other productive land uses compete with environmental and biodiversity goals *[8-10]*. Balancing or trading-off land use values in both space and time is a huge challenge *[11-14]*. Competing land uses can occur at landscape to local scales, where specific land uses are prioritized over others *[12,15]*.

A major form of land use conflict globally can occur in natural forests that are not only important for water production but are also targeted for timber and pulpwood production *[16,17]*. Here, we explore trade-offs in water yield resulting from logging in the forested water catchments, north-east of Melbourne – the second largest urban settlement in Australia with a current population of five million people *[18]* and the nation's fastest growing city *[19]*. These catchments produce the majority of water for Melbourne and many surrounding towns, as well as some agricultural areas *[20]*. The same region is also an important source of pulpwood for paper manufacturing and sawlog for timber production *[21]*. It has long been recognized that logging has a negative impact on water yield *[22-25]* and historical documents reveal long-term conflicts between water yield and timber production in these water catchments dating back well over a century *[26]*. However, the effects on water yield resulting from past logging (dating back many decades), combined with potential scenarios for altering logging regimes in the future, have rarely been quantified.

Given this, we conducted an indicative analysis of the impacts of historical, as well as future logging, on water yield in the Thomson Catchment, the largest of five major forested catchments supplying Melbourne and the only one where extensive logging is currently conducted. The Thomson Catchment has been subject to logging since the 1920s *[27]*. During the drought of 1967/8, the first diversions of water were taken from the Thomson River and weirs were then built in the 1970s. It became a designated water catchment following the completion of the Thomson Reservoir in 1983 *[26]*. Whereas most of Melbourne's other water catchments were closed to all forms of industrial timber and pulpwood extraction upon their respective declaration as water supply catchments, logging was allowed to continue in the Thomson Catchment following its designation *[26]*.

In this study, we modelled changes in water yield in relation to forest age in the Thomson catchment resulting from: (1) past logging and regeneration; and (2) future forest management scenarios. Our focus is on an assessment of the spatial impacts of disturbance across the Thomson catchment on water yield. The change in forest structure due to the age of forest stands that are logged or that are burned in a high severity bushfire has significant implications on evapotranspiration, which is the product of leaf transpiration and interception and soil evaporation losses *[28]*. As forests age after disturbance, the stocking density of the overstorey reduces from millions of seedlings per hectare, to thousands of stems per hectare in young regrowth, to typically less than 50 stems per hectare in old growth *[29]*. It is the change in the density of forest stands with age that produces a marked difference in evapotranspiration and thus streamflow *[28]*. In this context, the legacies of past forest management practices can persist for many decades, if not centuries *[30]*. These legacies may potentially compound the impacts of projected changes in land use or climate change *[31]*. Understanding potential future changes in these drivers and their effects on land-use and sustainability in resource use across space and over time is critical for guiding strategic decisions that can help land managers adapt to change, anticipate opportunities, avoid disasters, and cope with surprises.

## Methods

### *Study area*

Our study area is the Thomson Water Supply Catchment, which covers approximately 48,700 hectares. The catchment provides water to the Thomson Reservoir, approximately 125km east of the city of Melbourne (Figure 1). The Thomson Reservoir was completed in 1983 and was designed to build up water reserves in wet years for use in dry years *[26]*. The catchment is located on the southern side of the Great Dividing Range. The terrain is steep and deeply incised with elevation ranging from 300m to 1,520 metres above sea level. Mean annual precipitation ranges from 1000mm to 2,500mm across the catchment, increasing with increasing elevation *[32]*.

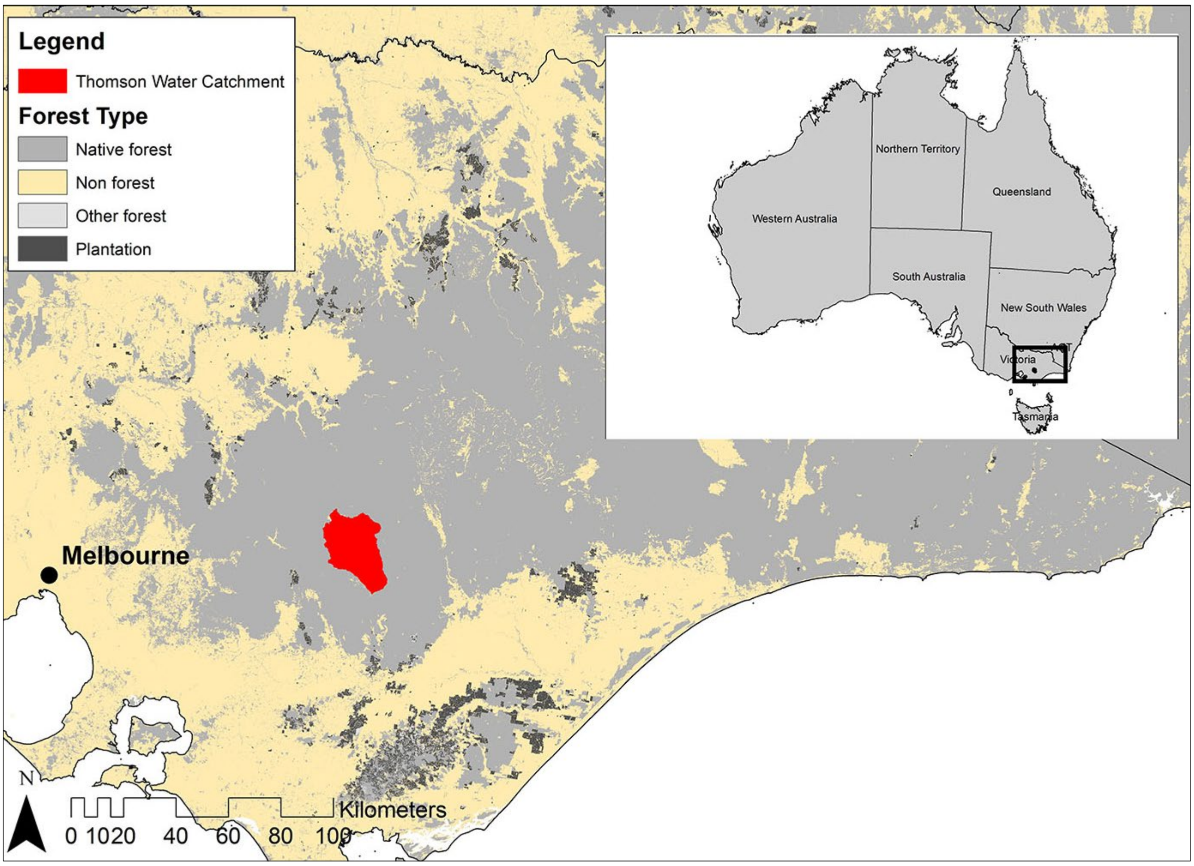


**Figure 1. Location of the Thomson Water Supply Catchment**

The Thomson Reservoir can hold up to 1,068 billion litres or 59% of Melbourne's total water storage capacity of 1,812 billion litres (Table 1) *[33]*. It is the largest reservoir of the Melbourne Water Supply system. As of 27 October 2018, the Thomson Reservoir held 662,805 ML or 57% of Melbourne's Water Supply. The Thomson Reservoir is also the largest on-stream reservoir, whereby it is solely reliant on streamflow from rainfall across its surrounding water catchment. In addition to the Thomson Reservoir, the Melbourne Water Supply system also consists of five other on-stream reservoirs: Upper Yarra, Maroondah, O'Shannassy, Yan Yean and Tarago Reservoirs (Table 2). The Thomson Reservoir holds around 78% of total on-stream water supply capacity, as well as current on-stream capacity (as of 27 October 2018).

The Thomson Catchment supplies water to the Upper Yarra Reservoir. Over one billion litres of water per day can be transferred from the Thomson Reservoir to the Upper Yarra Reservoir *[34]*. Water is then transferred to the Silvan and Cardinia Reservoirs. These are off-stream reservoirs that hold water for distribution throughout the Melbourne metropolitan area (Figure 2). Along with the smaller catchments of Armstrong, McMahon's, Starvation and Cement Creeks, the O'Shannassy Reservoir also supplies the Silvan and Cardinia Reservoirs. These reservoirs and catchments also provide water to the Yarra River, whereby water is pumped from further downstream to the Sugarloaf Reservoir, another off-stream reservoir *[35]*.

Of the four largest 'onstream' reservoirs (Thomson, Upper Yarra, Maroondah and O'Shannassy), the Thomson Reservoir receives the highest volume of combined catchment system streamflow, thus making it the most important reservoir of the Melbourne Water Supply system (Figure 3). Of the 491,010 ML flowing out of the four major catchments annually, the Thomson receives around 202,930 ML per annum or 41% of total water inflow *[34]*. The next largest inflow comes from the adjoining Upper Yarra Catchment, with an annual catchment inflow of 122,260 ML. The remaining on-stream reservoirs of Maroondah and O'Shannassy receive smaller annual inflows of 76,000 and 90,000 ML annually.

**Table 1. Water storage levels: 27 October 2018** *[36]*

| Reservoir | Total capacity (ML) | % of Total Capacity | Current volume (ML) | % of Current Volume |
|---|---|---|---|---|
| Thomson | 1,068,000 | 59% | 662,805 | 57% |
| Cardinia | 286,911 | 16% | 184,927 | 16% |
| Upper Yarra | 200,579 | 11% | 114,606 | 10% |
| Sugarloaf | 96,253 | 5% | 60,111 | 5% |
| Silvan | 40,445 | 2% | 35,182 | 3% |
| Tarago | 37,580 | 2% | 31,050 | 3% |
| Yan Yean | 30,266 | 2% | 24,713 | 2% |
| Greenvale | 26,839 | 1% | 24,719 | 2% |
| Maroondah | 22,179 | 1% | 18,007 | 2% |
| O'Shannassy | 3,123 | 0% | 1,915 | 0% |
| Total | 1,812,175 | 100% | 1,158,035 | 100% |

**Table 2. On-stream water storage levels: 27 October 2018** *[36]*

| On Stream Reservoirs | Total capacity (ML) | % of Total Capacity | Current volume (ML) | % of Current Volume |
|---|---|---|---|---|
| Thomson | 1,068,000 | 78% | 662,805 | 78% |
| Upper Yarra | 200,579 | 15% | 114,606 | 13% |
| Tarago | 37,580 | 3% | 31,050 | 4% |
| Maroondah | 22,179 | 2% | 18,007 | 2% |
| O'Shannassy | 3,123 | 0% | 1,915 | 0% |
| Yan Yean | 30,266 | 2% | 24,713 | 3% |
| Total | 1,331,461 | 100% | 828,383 | 100% |

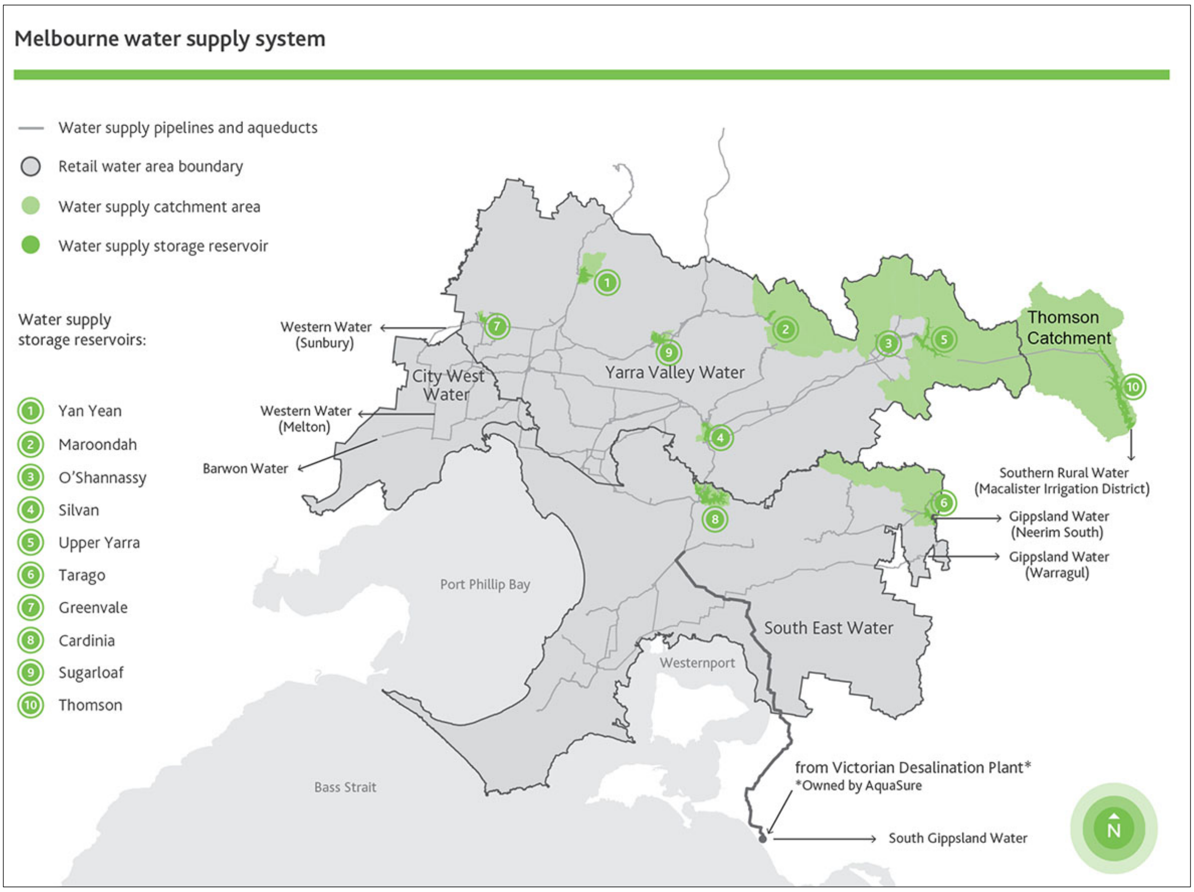


**Figure 2. Melbourne Water Supply Network showing the Thomson Catchment, other water supply catchments, reservoirs, rivers and transfer pipelines** *[37]*

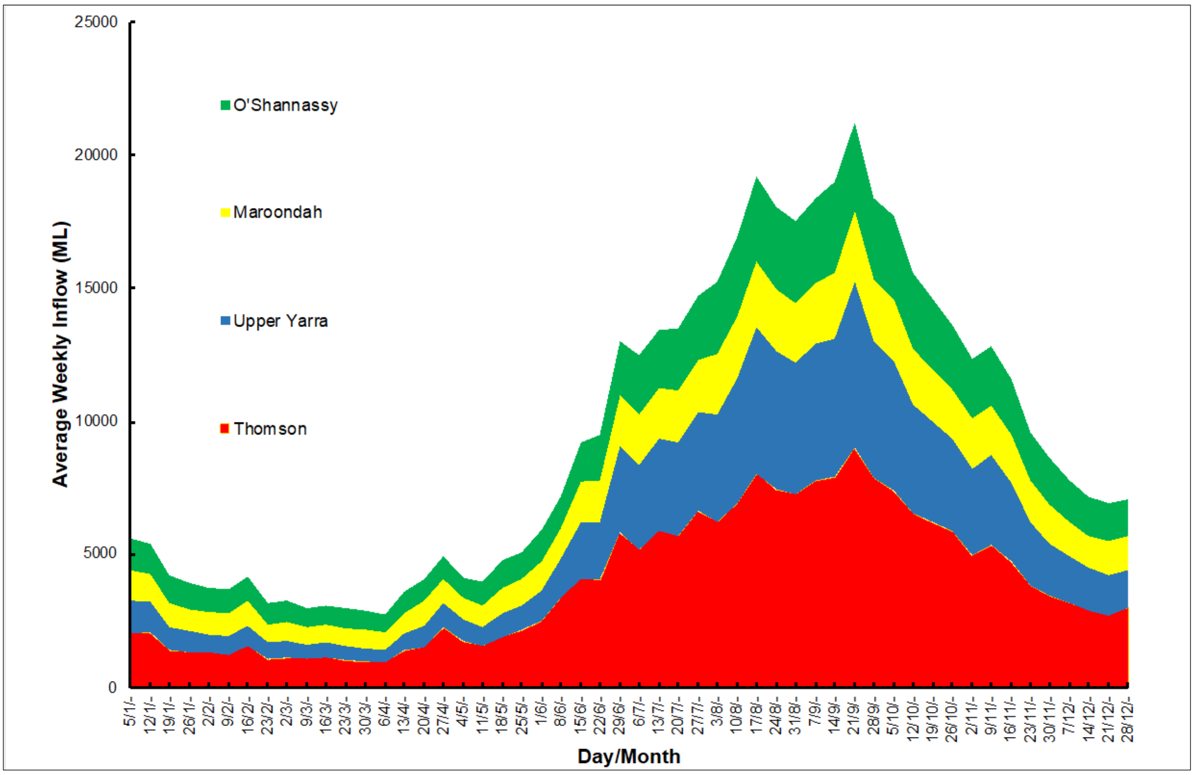


**Figure 3. Average weekly inflow to four major water supply reservoirs: The Thomson, Upper Yarra, Maroondah and O'Shannassy Reservoirs** *[34]*

### *Land tenure*

The land tenure of the Thomson Catchment is mostly state forest, with a smaller area protected within the Baw Baw National Park (Figure 4). State forest covers the majority of the catchment, consisting of nearly 41,000 hectares or 92% of the catchment (Table 3). Of this, nearly 29,000 hectares or 65% of the catchment area is designated as General Management and Special Management Zones, where logging is permitted. Informal reserves, such as Special Protection Zones, consist of over 12,000 hectares or 27% of the catchment. Formal protected areas, consisting only of the Baw Baw National Park, covers 3,517 hectares or 8%.

**Table 3. Land tenure across the Thomson Catchment (forested areas excluding water)**

| Land tenure | Area | Status | % of Total |
|---|---|---|---|
| General Management Zone | 27,981 | Logging Permitted | 63% |
| Special Management Zone | 747 | Logging Permitted | 2% |
| Special Protection Zone | 12,153 | Logging excluded | 27% |
| National Park | 3,517 | Logging excluded | 8% |
| Historic Reserve | 10 | Logging excluded | 0% |
| Reservoir Park | 1 | Logging excluded | 0% |

The land tenure classification of the Thomson Catchment is different to the other remaining large on-stream catchments of Upper Yarra, O'Shannassy, Maroondah and Wallaby Creek (supplying Yan Yean), because all of these catchments have been designated as 'closed' and protected catchments. These catchments were vested by the then Melbourne and Metropolitan Board of Works (MMBW) in 1890s *[22]* and were included in the Yarra Ranges and Kinglake National Parks over a century later *[38]*. Logging and public access were restricted in order to protect the water supply capacities of those catchments, but the Thomson Catchment was not afforded the same levels of protection *[26]*.

The Thomson Catchment is within a designated area subject to a Legislative Supply Agreement between the Victorian Government and a pulp and paper production company, Paper Australia Pty Ltd, owned by the Nippon Paper Group *[39]*. The Legislative Supply Agreement, otherwise referred to as the *Forests (Wood Pulp Agreement) Act 1996*, binds the state to supply the company with a specified volume of pulp logs from the Thomson Catchment and surrounding region over a 34 year period between 1996 and 2030 to its processing facility at Maryvale *[40]*. The first Wood Pulp Agreement was passed in 1936 and it contained a clause in which logging and other extraction activities were to cease by 1967, when the Thomson Catchment was intended to be designated a water supply catchment *[41]*. However, a revision of the Agreement in 1961 removed this clause, thereby allowing logging to continue following the designation of the Thomson Water Supply Catchment *[42]*.

### *Forest types*

The Thomson Catchment supports several forest types, with Sub-alpine (Snow Gum – *Eucalyptus pauciflora*) woodland dominating the highest elevations on the Baw Baw Plateau, the ash forests dominating the higher elevation slopes along the northern and eastern escarpments of the Baw Baw Plateau and mixed species forests, including Messmate (*Eucalyptus obliqua*), dominating the remainder of the catchment (Figure 5). The ash forests form the focus of this study because they are located across the higher rainfall area of the catchment (Figure 6). This forest type is dominated by three sub-forest types: Mountain Ash (*Eucalyptus regnans*), Alpine Ash (*Eucalyptus delegatensis*) and Shining Gum (*Eucalyptus nitens*) (Figures 7, 8 and 9). Collectively, these forest types are referred as 'ash forest'.

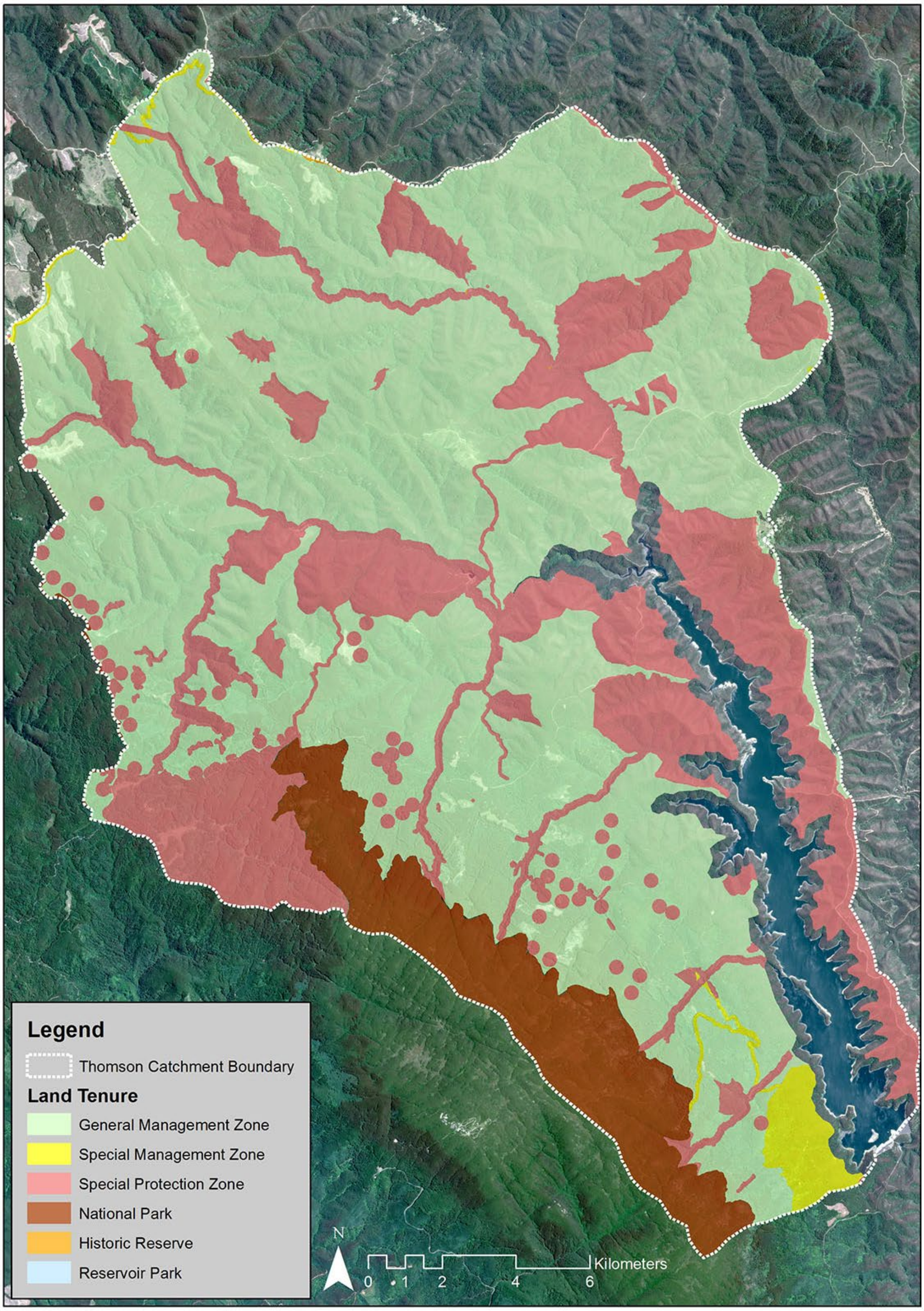


**Figure 4. Land tenure across the Thomson Catchment**

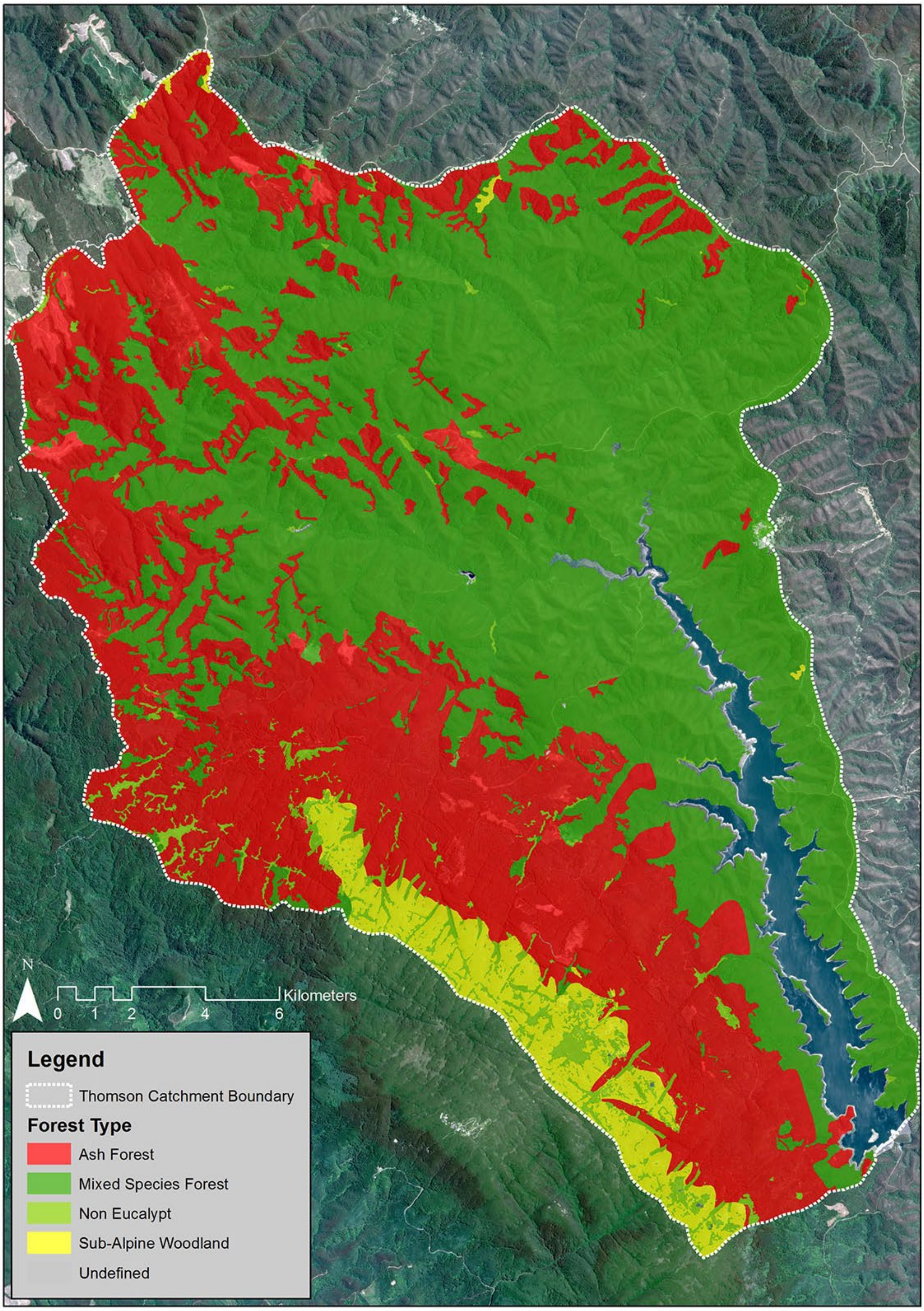


**Figure 5. Tree species distributions across the Thomson Catchment** *[53]*

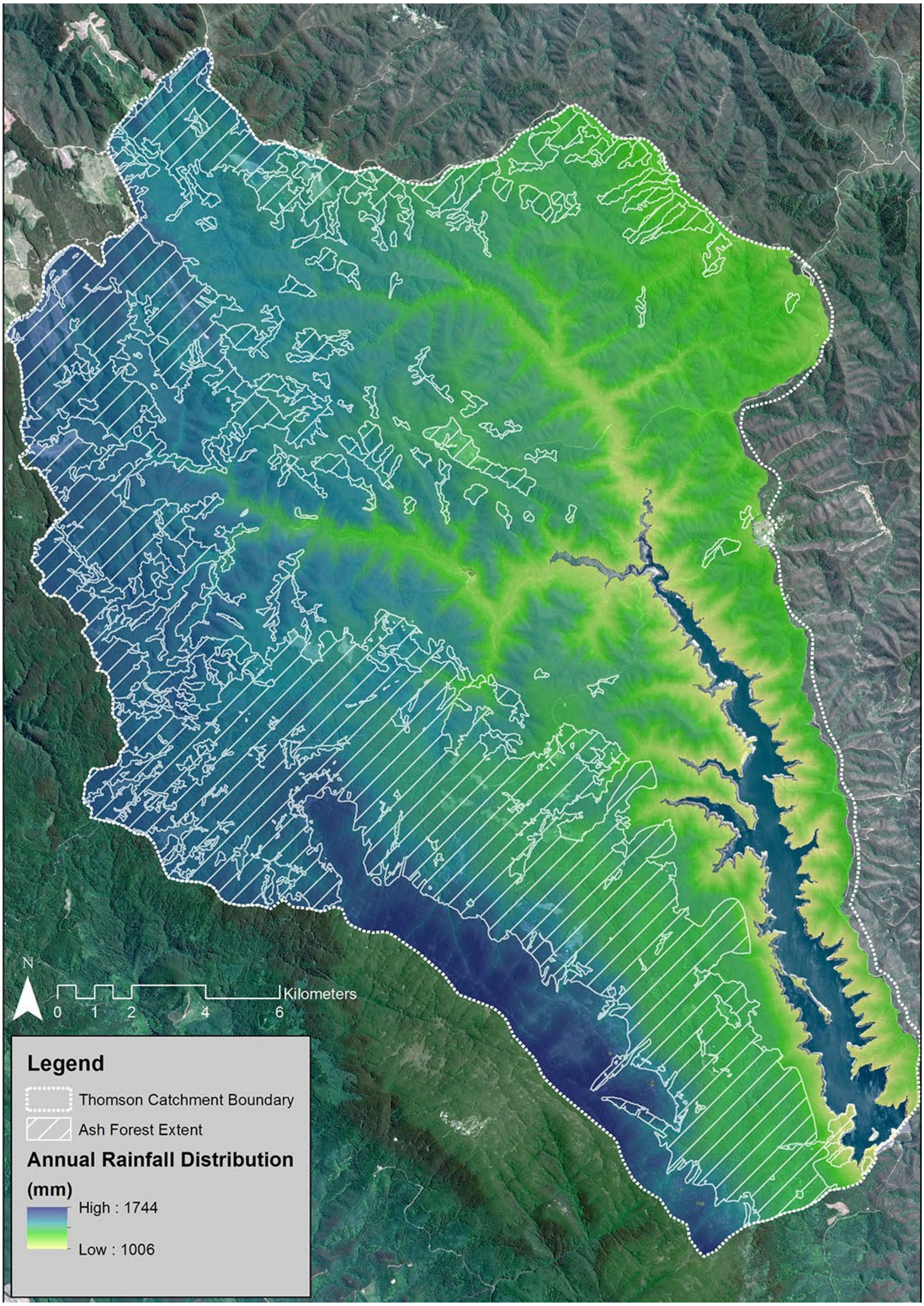


**Figure 6. Annual rainfall over the Thomson Catchment with Ash Forest extent** *[53,54]*

**Figure 7. Mountain Ash forest on the south face of the Baw Baw Plateau near the Thomson Catchment** (Photo: C. Taylor)

**Figure 8. Alpine Ash forests along the northern escarpment of the Baw Baw Plateau in the Thomson Catchment** (Photo: C. Taylor)

**Figure 9. Shining Gum Forests along the southern escarpment of the Baw Baw Plateau, adjacent the Thomson Catchment** (Photo: C. Taylor)

The ash forests are characterised by iconic and visually spectacular stands of tall trees. These forests are restricted to the mountainous and highest rainfall areas of the state, occupying only 547,000 hectares or less than 7% of Victoria's total forest cover of 8.2 million hectares *[43]*. Mountain Ash are the tallest of the ash forests and can exceed more than 100 metres in height *[29]*. The structure of ash forests can be either even-aged or multi-aged, depending on the disturbance history *[44]*. Even-aged stands result if high-severity fires burn through the forest. However, large wildfires can be variable in severity and, if they burn at low severity and overstorey trees survive, multiple age cohorts can develop *[45]*. These multi-aged forests contain old growth trees interspersed with younger trees. Mountain Ash forests are typically monotypic *[46]* but feature a diverse understorey *[47]*. Alpine Ash occurs at higher elevations than Mountain Ash forests and are usually monotypic under optimum conditions *[48]*. Shining Gum forests generally occur as small patches amongst more extensive stands of Mountain and Alpine Ash forest across the catchment *[49]*. Importantly, both human disturbance (i.e. logging) and natural disturbance (high severity bushfire) within the ash forests are typically stand-replacing events *[31]*.

Ash forests cover 18,871 hectares within the Thomson catchment (Table 4) and provide habitat for rare and threatened fauna, including the Critically Endangered Victorian endemic, Leadbeater's Possum (*Gymnobelideus leadbeateri* McCoy) *[50]* and Baw Baw Frog (*Philoria frosti* Spencer) *[51]*, as well as the Vulnerable Greater Glider (*Petauroides volans* Kerr) *[46]*. These forests contain nationally significant landscapes, including a site of Global Zoological Significance located around Mount Baw Baw *[52]*.

**Table 4. Forest type areas across the Thomson Catchment**

| Forest Type | Area (ha) | % of Total |
|---|---|---|
| Ash Forest | 18,871 | 40% |
| Mixed Species Forest | 24,973 | 53% |
| Snow Gum | 1,974 | 4% |
| Non-Eucalypt | 1,312 | 3% |
| Undefined | 31 | 0% |
| **Total** | **47,162** | **100%** |

## Forest management and logging

The ash forests of the Thomson Catchment are considered an important resource for the native forest logging industry in Victoria *[55]*. Clearfelling is the main form of logging in the ash forests *[56]*. It is the most intensive of all silvicultural practices, where all the merchantable logs are removed from a defined area of forest (or 'coupe') and part of the remaining debris is burnt in a high intensity slash-fire (Figure 10) *[21]*. This creates an ash bed, upon which the commercially valued eucalypt species are aerially seeded or replanted. Following logging or fire, the regenerating eucalypt seedlings gradually self-thin as they grow at 1.5 to 3.0 m in height per year *[29]* until their top height is reached *[57]*.

To analyse impacts of logging across the catchment, we obtained historic logging data from the State Forest Resource Inventory (SFRI) *[53]*, logging history *[58]*, data on fire disturbance history *[59]* and information on Ecological Vegetation Classes (EVC) *[60]*. No major or widespread fires (exceeding 1,000 hectares) have burnt in the catchment since the bushfires of 1939 *[59]*. The most extensive disturbance in the catchment since the 1939 bushfires has been logging. The area available to logging across the Thomson Catchment is around 8,190 hectares *[55]*.

No data are currently available on the volume of sawlogs and pulplogs extracted specifically from the Thomson Catchment, because sawlogs and pulplog reporting is conducted statewide. We used data derived from previous work in the Wood and Water Project *[55]*, together with information extrapolated from statewide native forest log production data published annually *[61]*.

**Figure 10. Clearfell logging in the Thomson Catchment with the Thomson Reservoir in the background and a remaining seed tree on the right** (Photo: Chris Taylor)

***Scenarios for water yield and forest disturbance modeling***

We modelled four scenarios to assess the impacts on water yield of past and current forest management and associated logging, together with alternative future management pathways (Table 5). For Scenario (1), we modelled a baseline of water yield from the historic forest management and associated logging, together with a future projection of continued logging, based on annual logging rates set by VicForests for the period between 1997 and 2017. For Scenario (2), we modelled the water yield assuming no historical or future logging. We used this modelling to quantify the water yield impacts of past, current and future management relative to the baseline scenario. For Scenario (3), we modelled historic logging and cessation of logging in 1967, which was originally planned under the Wood Pulp Agreement Act 1936, but cessation never occurred *[41]*. For Scenario (4), we modelled a cessation of logging in 2018. For the purposes of this study, we did not include the impacts of future fire or climate change, as our study focused specifically on the impacts of forest management on water yield.

**Table 5. A brief overview of the four scenarios modelled in this study.**

| Scenario | Description | Description |
|---|---|---|
| **1** | Baseline | Historic forest management and logging across the catchment. Continued logging into the future |
| **2** | No logging | Catchment not subject to any logging – historic or future logging |
| **3** | Cessation of logging in 1967 | Logging ceasing in 1967, as per the Wood Pulp Agreement 1936 |
| **4** | Cessation of logging in 2018 | Logging ceases by the end of 2018 |

## Modelling catchment water yields

A stand age/streamflow relationship for Mountain Ash forests was generalised by Kuczera *[62]* using rainfall and runoff data collected from forested catchments completely or partially burnt by the wildfires in 1939. The relationship between forest age and water yield is represented by the 'Kuczera curve' (Figure 11). This curve has wide error bands indicating uncertainty around the absolute impact on yield *[28]*. Of crucial importance is the evidence about the age of the ash forest just prior to the 1939 fires suggesting that the yield trend curve must exhibit a long-term recovery with average yields approaching a stationary value by about age 100-150 years. The approach specifies a general equation for the post-1939 yield curve and estimates its parameters using available streamflow data:

$$g(t) = L_{max}K(t-1941)e^{[1-K(t-1941)]},\ if\ t \geq 1941 \qquad (1)$$

where g(t) is the reduction in average annual yield (mm) following the 1939 fire, and $L_{max}$ and K are yield parameters. $L_{max}$ is the maximum yield reduction (mm) following the fire and *t* is the time (years) from the commencement of the yield reduction to its maximum *[62]*.

The equation used in this study was modified from Kuczera *[62]* as per Read Sturgess and Associates (1994). The equation was modified to model disturbance occurring following logging and/or other disturbance and to calculate change in yield across the catchment:

$$Y = M - L_{max}(t-2)e^{1-K(t-2)},\ if\ t \geq 2 \qquad (2)$$

where *Y* is the water yield (ML/ha/year), M is the water yield from mature forest, $L_{max}$ is maximum yield reduction below that of mature forest, *t* is time in years since disturbance and *K* is reciprocal of time taken for maximum yield depression. Pre-disturbance yield is 11.9 ML/year, with maximum yield reduction following disturbance being 6.1 ML/year (Table 6).

The Kuczera equation does not include an initial yield increase immediately following stand mortality from fire or logging. In practice, there is an initial increase in water yield, typically of 5-10 years duration, while evapotranspiration is reduced, followed by a decline in yield as evapotranspiration is increased as the stand regenerates *[28]*.

**Table 6. Parameters used in equation 2** *[63]*

| Parameter | Value | Unit |
|---|---|---|
| *M* | 11.9 | ML/ha/year |
| *Lmax* | 6.1 | ML/ha/year |
| *K* | 0.039 | |

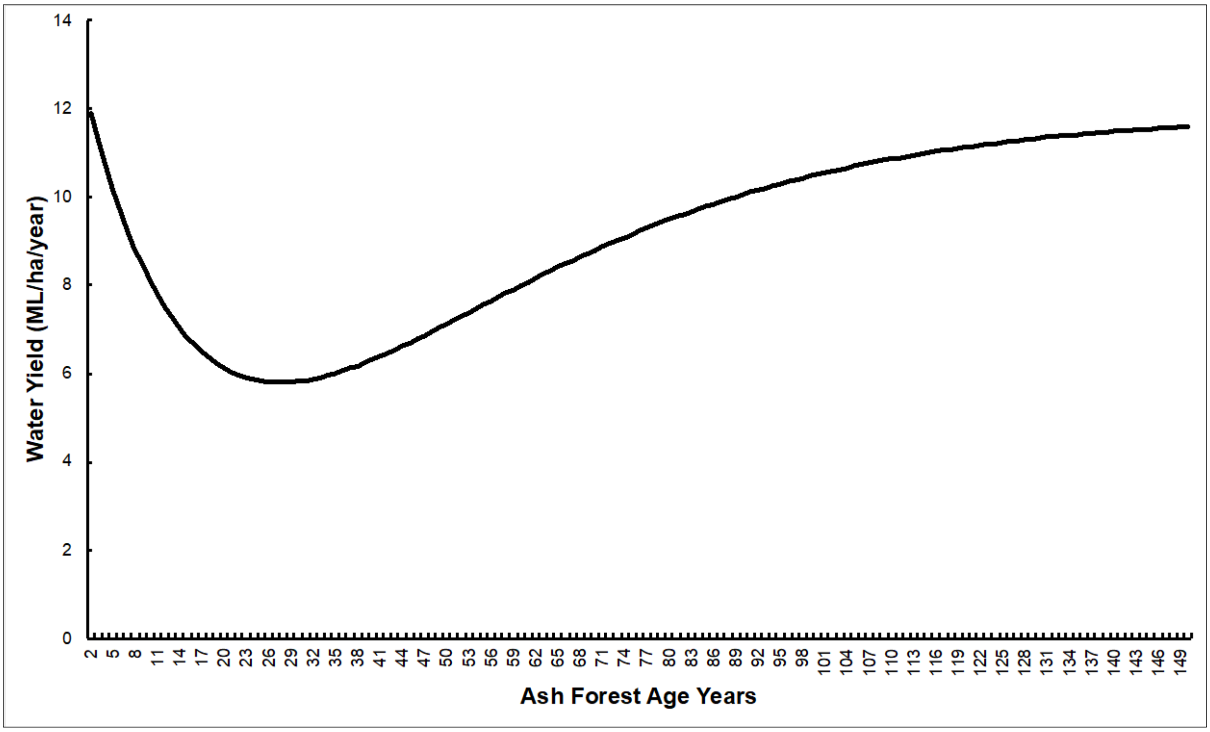


**Figure 11. Kuczera relationship for water yield from regrowth ash forest after bushfire based on an extrapolation by Read Sturgess and Associates** *[63]*

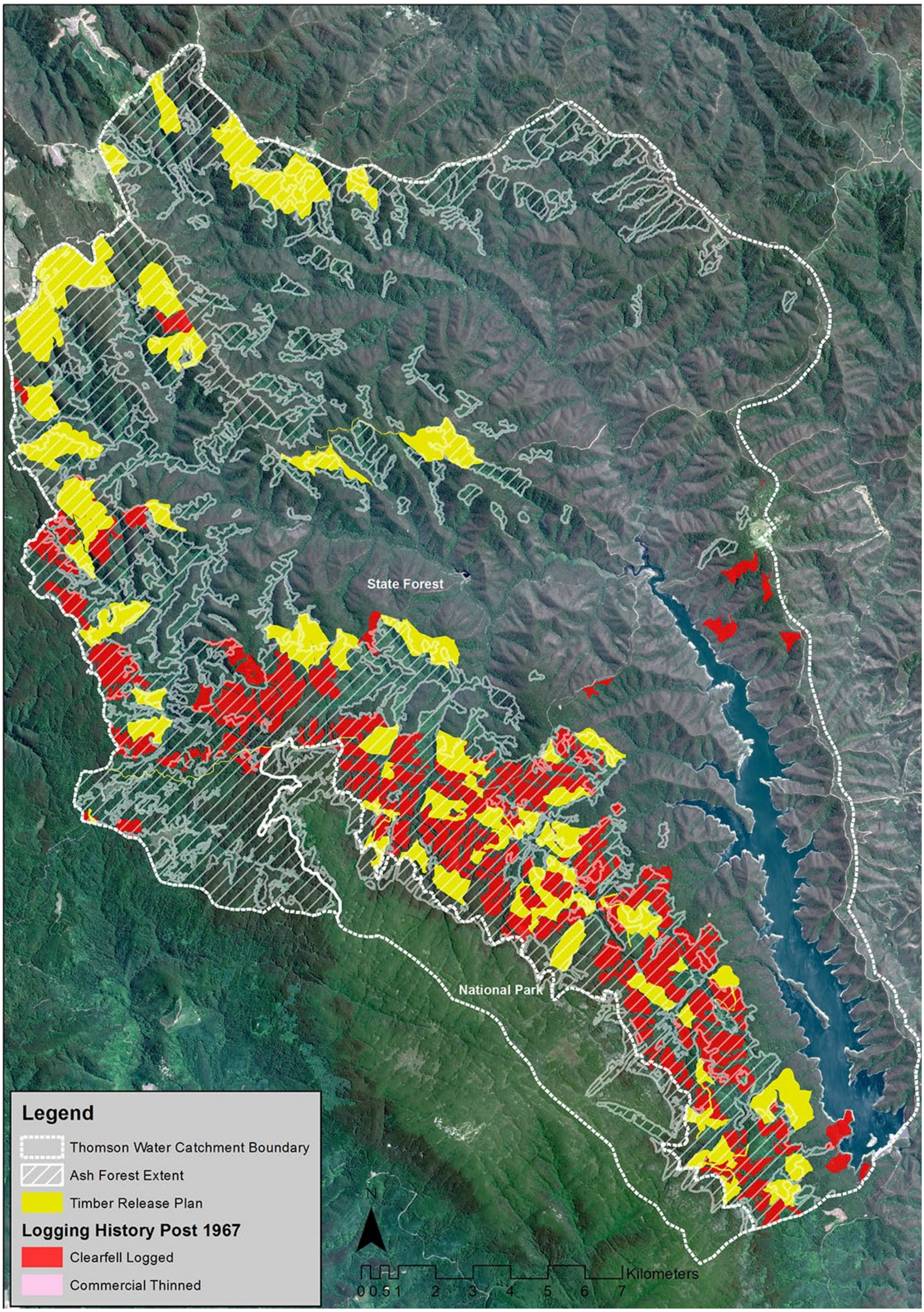


**Figure 12. Logging history (post 1967) and the current Timber Release Plan Overlay in the Thomson Catchment** *[58,64]*

## Results

### *Disturbance across the catchment*

In total, approximately 8,250 hectares or 17% of the Thomson catchment has been clearfell logged (ash and mixed species forests) since the 1939 bushfires. Around 81% of all logging is concentrated across the ash forests throughout the catchment (Figure 12). Of this area, an estimated 7,790 hectares has been clearfell logged, comprising 94% of all clearfell logging occurring across all forest types across the catchment (Table 7). Since the 1939 bushfires, around 45% of the ash forests have been clearfell logged.

The temporal distribution of clearfell logging occurs across two major time periods: immediately following the 1939 fire in the early 1940s and between the years 1989 and 2004 (Figure 13). In 1944, nearly 2,273 hectares of ash forest was logged, along with 53 hectares of mixed species forest (Table 8). This was part of an extensive salvage logging operation that occurred at the time *[44]*. Between 1950 and 1988, an average of 72 hectares of ash forest was logged each year, along with 26 hectares of mixed species forest. Between 1989 and 1999, the annual average area of clearfell logging increased to 182 hectares in the ash forests, along with 5 hectares of mixed species forest. The largest area of ash forest clearfell logged was 294 hectares in 1990. Approximately 4,619 hectares of ash forest is now younger than 40 years (Figure 14).

Over 4,000 hectares in the Thomson Catchment is currently assigned under the Timber Release Plan issued by VicForests in 2016 *[64]*. Similar to historic logging, approximately 84% of the area proposed for cutting is within the ash-type forests of the catchment.

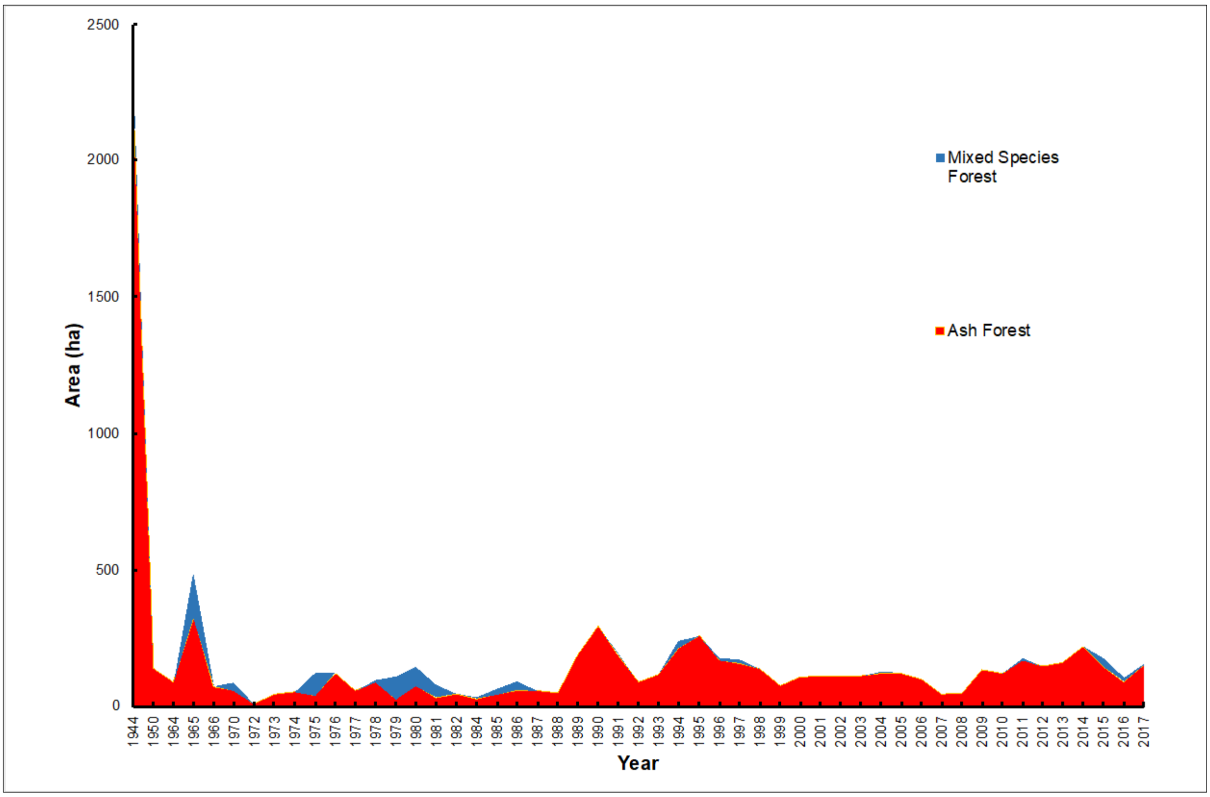


**Figure 13. Temporal distribution of clearfell logging in the Thomson Catchment**

**Table 7. Area (ha) of disturbance since 1939 across Ash forest in all state forest (unprotected) and the Baw Baw National Park (protected) sections of the Thomson Catchment**

| Disturbance | Ash Forest (ha) | Total Forest (ha) |
|---|---|---|
| Clearfell Logged | 7,790 | 8,250 |
| Commercial Thinned | 1 | 1 |
| Logged - Other | 590 | 2,137 |
| Reforestation | 40 | 51 |
| Road Alignment | - | 4 |
| Unlogged | 10,350 | 36,718 |
| **Total** | **18,771** | **47,161** |

**Table 8. Average annual area of forest that was subject to clearfell logging over various time periods**

| Period | Ash clearfell logged pa (ha) | Mixed spp clearfell logged pa (ha) |
|---|---|---|
| 1944 | 2,273 | 53 |
| 1950-1988 | 72 | 26 |
| 1989-1999 | 182 | 5 |
| 2008-2017 | 149 | 6 |

**Table 9. Modelled water yield runoff from the ash forests across the Thomson Catchment**

| Scenario | Description | Water Yield Runoff modelled for 2018 | Water Yield Runoff modelled for 2050 |
|---|---|---|---|
| **1** | Baseline | 164,290 | 172,047 |
| **2** | No logging | 179,658 | 207,203 |
| **3** | Cessation of logging in 1967 | 177,788 | 206,247 |
| **4** | Cessation of logging in 2018 | 164,290 | 187,054 |

**Table 10. Reduction in water yield as a result of logging ash forests under Scenarios 1, 3 and 4, compared with Scenario 2 across the Thomson Catchment**

| Scenario | Description | Reduction in water yield in ML compared with Scenario 2 (No logging) by 2018 | Reduction in water yield in ML compared with Scenario 2 (No logging) by 2050 |
|---|---|---|---|
| **1** | Baseline | 15,368 | 35,156 |
| **3** | Cessation of logging in 1967 | 1,870 | 956 |
| **4** | Cessation of logging in 2018 | 15,386 | 20,149 |

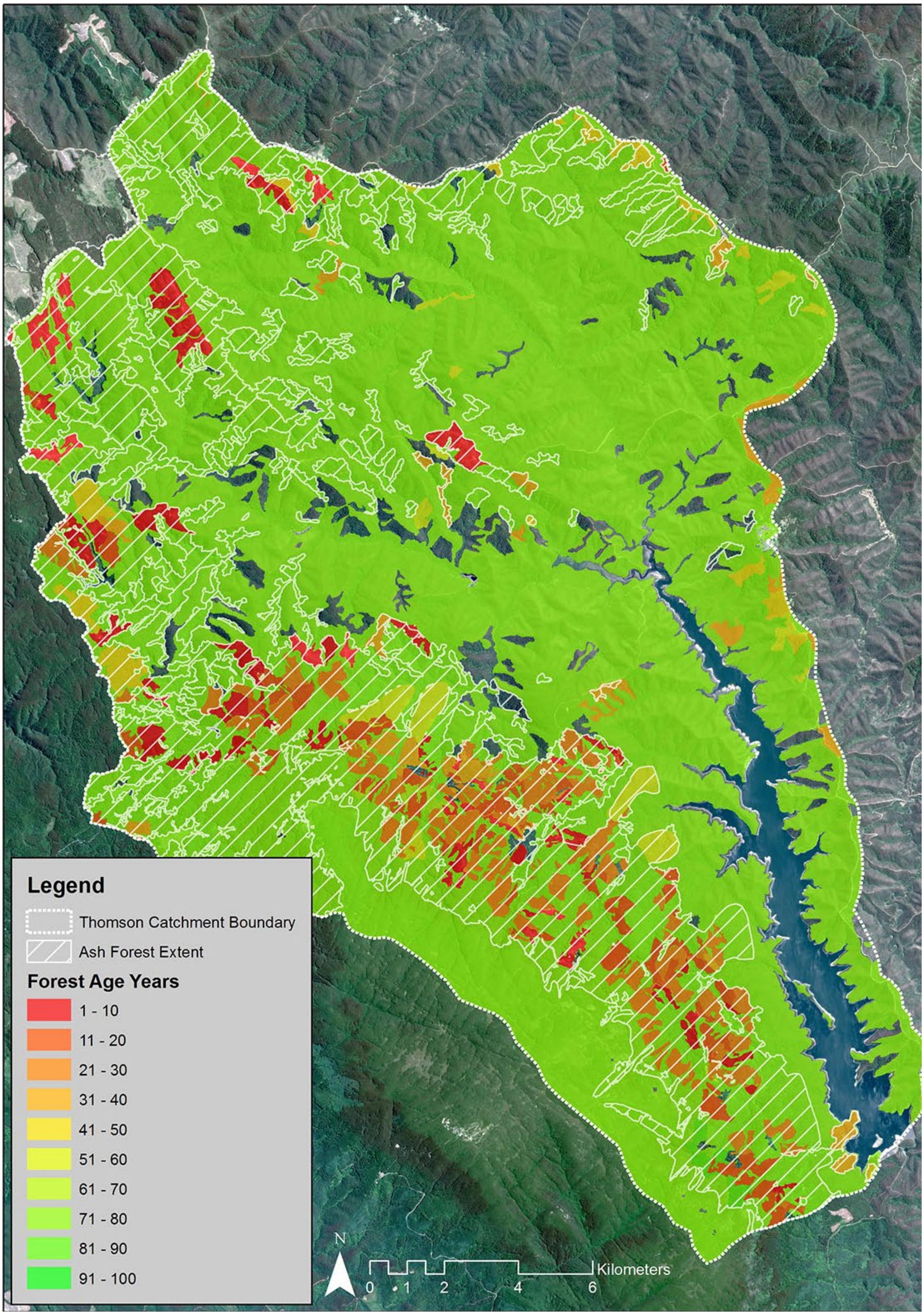


**Figure 14. Forest age class distribution across the Thomson Catchment** *[53]*

***Modeled water yields***

Using the Kuczera equation, we found that the 1939 fires had the greatest impact on water yield, with a reduction exceeding 114,407 ML modelled for the ash forests per year by 1964 (Figure 15). Salvage logging in 1944 is assumed to have occurred in fire-killed stands and damaged regenerating forests. As regrowing ash forest matured, the water yield runoff increased from 111,938 ML in 1964 to 148,574 ML in 1998. From 1998, Scenarios (1) and Scenario (4) deviate from Scenarios (2) and (3) as the increase in clearfell logging from 1989 begins to take effect (Figure 16).

By 2018, the water yield runoff for Scenario (1) was 164,290 ML per annum (Table 9), but our modelling projects a reduction in water yield exceeding 15,368 ML annually compared with Scenario (2) (Table 10). The projected loss under the Scenario (1) increases to nearly 35,156 ML by 2050.

Under Scenario (3), only a small annual reduction of 1,079 ML is modelled as being lost annually over the period from 1967 to 2018. This loss is a result of logging occurring prior to 1967. This is modelled to remain constant through to 2050.

Under Scenario (4), we project that around 20,149 ML would be returned to the Thomson Catchment by 2050, compared with Scenario (2). Comparing the water yield difference between Scenario (1) and Scenario (4), we modelled that around 15,000 ML would be returned to the catchment by 2050.

In all scenarios, there is an assumption of no wildfires occurring.

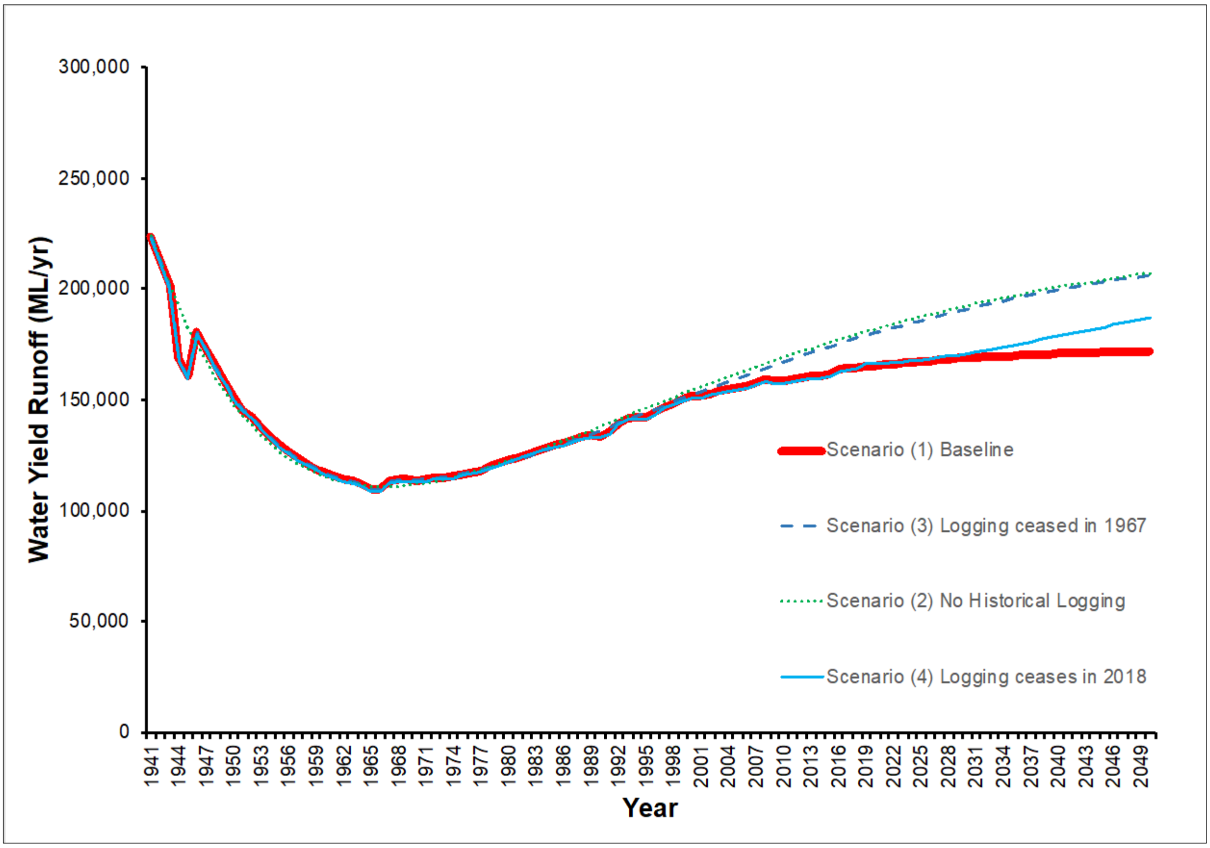


**Figure 15. Water yield runoff for Scenarios (1) Baseline, (2) No logging, (3) Cessation of logging in 1967 and (4) Cessation of logging in 2018, based on the equation developed by Kuczera** *[62]*

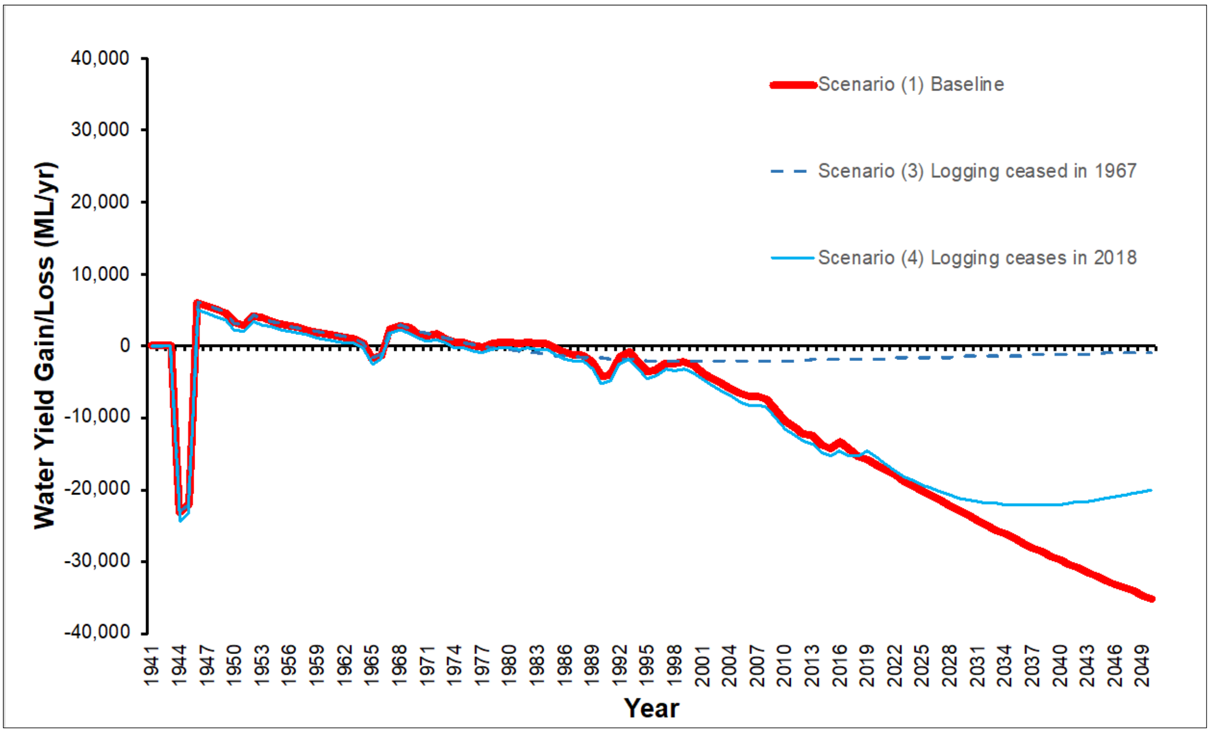


**Figure 16. Water yield gain/loss for Scenarios (1) Baseline, (3) Cessation of logging in 1967, and (4) Cessation of logging in 2018, compared against Scenario (2) No logging**

## Discussion

The management of native forests has been one of the most contested environmental issues on social, political and scientific agendas in Australia for the past 50 years *[65,66]*. This is, in part, because Australia has a relatively limited area of productive forest compared to its overall land area *[67]*. Indeed, demand for the use of low relief, high rainfall and high-productivity landscapes for logging, farming, water production, tourism and urban development far exceeds the capacity of these forests to supply all of these services *[68]*.

Here, we conducted an indicative spatial and temporal analysis of the effects of wood production on water production in a forested catchment that is a critical part of the water supply for the city of Melbourne. It is hoped our study will help better inform decision making regarding two competing land uses. Our focus is on spatial competition as the highest rainfall occurs in the most productive parts of the catchment, which is also the majority of logging takes place. Our analyses indicate that logging will result in a major reduction in annual water yield from the ash forests across Thomson Catchment of nearly 20% by 2050. Given this catchment contributes to over 40% of total stream runoff across the water catchment network for Melbourne, this has significant ramifications for both water security and wood supply. Thus, our investigation is a classic example of resource competition; that is, competition for land and forest for logging versus water production. In the remainder of this report, we discuss the key implications of our study for forest and water management, and then conclude with some policy recommendations regarding forest conservation.

### *Relationships between logging and water yield*

Our analyses indicated that past logging operations have led to an annual loss of 15,368 ML in water yield from the Thomson Catchment by 2018. Continued logging would add a further annual loss of between 15,000 ML from the Thomson Catchment by 2050, increasing it to over 35,000 ML. These changes represent an annual loss of 9% and 20% of the ash forest catchment yield for the years 2018 and 2050, respectively. Based on an estimated consumption of 161 litres of water per person per day *[37]*, this loss in water yield resulting from logging equates to the lost water for nearly 600,000 people by 2050. Such past and projected future reductions in water supply are non-trivial particularly given that:

1. The Thomson Catchment is a key part of the overall water supply network for the city of Melbourne *[26]*;
2. The reservoir in the Thomson Catchment has experienced a decline in annual inflow since its completion: for the years between 1984 and 1996, the annual inflow was 254,000 ML; the inflow reduced to an average of 159,000 ML between 1997 and 2010 during the Millennium Drought *[33]*;
3. Melbourne's human population has been growing at a rapid rate (and recently passed 5 million) and water consumption has been increasing *[18]*;
4. A report by the agency responsible for Melbourne's water supply (Melbourne Water) has highlighted major concerns about water security by 2030 *[69]*.

Past governments in Victoria have generally prioritized water production over wood production by closing several major water catchments to logging and other forms of anthropogenic disturbance *[26]*. The first Wood Pulp Agreement Act of 1936, which legislated the supply of pulplogs from Victorian state forests to the then Australian Paper Manufacturers (APM) facility at Maryvale, featured a clause where logging was to cease following the designation of the Thomson Catchment in 1967 *[41]*. This did not occur; of all the logging (by area) that has occurred in the catchment, 63% has occurred since 1967. Moreover, the current Timber Release Plan, which assigns areas of forest for logging, covers a further 3,346 hectares or 17% of ash forests across the Thomson catchment.

Our work further quantifies the extent of loss of water yield associated with past logging operations and the likely future losses as a result of ongoing logging (Figures 15 and 16). It is more likely that our analyses underestimate, rather than overestimate water losses due to logging because of simplifications and assumptions that underpinned our analyses (see below).

***Previous studies modelling water yield changes in ash forests***

Several studies have shown that disturbance in ash forests alters water yield *[22,24,25,32,62,63, 70,71]*. Many of these studies were based on disturbance experiments in the Maroondah Catchment, first established during the 1950s and 1960s *[71]*. The 1980 study by Ronan and Duncan *[72]* in the Maroondah Catchment modelled average water yield reduction of 140mm or 0.14 ML/ha of water yield by 2075 as a result of logging on 60 year rotations commencing in the Maroondah Catchment by 1985. Later, the analysis in 1994 by Read Sturgess and Associates *[63]* modelled a number of alternative forests management scenarios and compared these with current management across the Thomson Catchment. One scenario modelled the cessation of logging in 1992, resulting in around 15,000 ML of water yield being returned to the catchment by 2050 *[63]*. These studies either used the equation by Kuczera *[62]* or earlier models where water yield was similarly correlated with the age of the forest *[22,63]*.

Changes to water yield in response to disturbance across the Thomson Catchment were later modelled using the Macaque model *[32]*. This model simulates temporal streamflow predictions quantified by the Kuczera equation, projecting changes in catchment water yield through changes in Leaf Area Index (LAI) and stomatal conductance *[73]*. The Macaque model calculates that ash forests across the Thomson Catchment are those where water yield is most affected by disturbance *[32]*. The Macaque model was used to model bushfire disturbance across the Thomson Catchment, where up to a 23% reduction in water yield was modelled under a scenario of frequent bushfires *[28,74]*. An additional study using the Macaque model simulated water yield losses resulting from logging across the Thomson Catchment, in addition to the multiple smaller water catchments where logging is also permitted. It modelled a series of forest management scenarios, whereby it was estimated that up to 16, 000 ML in water yield would have been returned to all of the water catchments by 2050 if logging had ceased in 2009/10 *[70]*.

## Caveats

The Kuczera equation is considered a useful representation of the potential impacts of forest disturbance on water yield runoff *[73]*. However, there are challenges in extrapolating this equation across a broader range of environmental conditions *[73]*. Our application of the Kuczera equation is indicative and further detailed analysis is required. The Macaque model can provide more detailed analysis through its representation of physical processes occurring within a water catchment *[32]*. However, there are challenges in the application of the model, because it contains over 70 parameters and most of them are default values *[73]*. Many of these parameters require calibration, for which data can be difficult to obtain for remote catchments *[75]*.

A simpler approach has been developed by Jaskierniak et al. *[75]* and Benyon et al. *[76]*, whereby fewer input parameters are used for modelling water yield across ash forests. These consist of the sapwood area derived from using the basal area of the forest, along with tree stocking density estimates generated in forest growth models. The benefits of using this model include greater certainty with input parameters. The model performs well, with $R^2$ values between 0.7 and 0.79. However, these parameters are reliant on extensive LiDAR mapping to obtain accurate estimates of the basal area and tree stocking density. The acquisition of such data was beyond the scope of this study.

Our analysis was underpinned by the assumption that current climatic conditions will remain unchanged until at least 2050 and hence across the full period of our projection. However, we are acutely aware there are substantial changes in climate taking place in our study region. Climatic conditions from 1950 to 1980 (half the data period) are significantly different to the present and the next 20 years will experience further change. Climate records *[77]* show 8 of the 10 hottest years on record for Australia have occurred in the last 10 years and Australia's average temperature has been below the long-term average only five times in the last 30 years and once in the last 10 years. Higher temperatures are typically associated with lower rainfall in south-eastern Australia and this combined effect would be expected to further reduce water yield. In addition, there are substantial effects of a warming climate on the frequency and extent of wildfire in the study region *[78]*. Indeed, a recent VEAC report noted that the area burned in the forests of the Central Highlands has increased substantially over historical records *[79]*.

We did not include well-known relationships between logging and fire severity in our projections of reduced water yield. Several studies have shown that logged and regenerated Mountain Ash and Alpine Ash forests are significantly more likely to burn at high severity than intact (undisturbed) stands *[80,81]*. These fires are typically stand-replacing events in Mountain Ash and Alpine Ash forest with the corresponding reduction in the age of the forest after the fire *[29]* leading to a reduction in water yield *[25,74]*.

## Policy recommendations

Our study has focused on the extent of past and likely future reductions in water yield from the Thomson Catchment. We have not sought to examine trade-offs in economic value associated with different forest uses. Other approaches are needed to do this such as integrated economic and environmental accounting (e.g. under the System of Environmental and Economic Accounting [SEEA]; *[82]*). Studies using this methodology have been completed for the wet forests of the Central Highlands of Victoria (which includes the forest in the Thomson Catchment) *[20]* and it shows that the economic value of the water for Melbourne is 25.5 times greater that the economic value of the timber produced in native forests. Therefore, solely on economic grounds, we suggest that ongoing logging of the Thomson Catchment does not appear to maximize the public good for resources from these forest areas.

One of the primary market drivers for logging across the Thomson Catchment is its inclusion within the current Legislative Supply Agreement area, as defined under the *Forests (Wood Pulp Agreement) Act 1996 [40]*. As this Act binds the Victorian Government to supply a minimum of 350,000m$^3$ of pulplogs from state forests per annum to the Maryvale Mills until 2030, there has been pressure to continue logging in the Thomson Catchment *[55]*. A transition from state forests to plantations was proposed for the Maryvale Mills in 2006 by its previous owner, PaperlinX Ltd, where it made a commitment to be using 100% plantation-sourced fibre for its printing and communication papers by 2017 *[83]*. This commitment was later abandoned, with the current owners of the Maryvale Mills arguing for continued access to state forests *[84]*. However, existing plantations across Victoria provided domestic and export markets with 3.9 million tonnes of hardwood pulplog in 2017 *[61]*. It is now technically feasible for the Maryvale Mills to source all of its hardwood pulplog intake from hardwood plantations across Victoria *[84]*. Indeed, plantation feedstock is often the preferred feedstock because of the length of the fibres and the pulp return per unit wood supplied *[84]*.

The case for sawlog supply presents challenges because very small volumes of hardwood plantation sawlog are produced in Victoria *[61]*. To address some of these challenges, a small sawmill in South Gippsland has already established a 1,500 hectares of a hardwood sawlog plantation, with the intent of generating 12,000m$^3$ of hardwood sawlogs per annum in 10-15 years *[85]*. In its 2017 Budget, the Victorian Government committed $110 million to establishing a plantation across in the Latrobe Valley to provide hardwood plantation sawlogs to mills *[86]*, but planting has not commenced *[87]*. Based on previous data and reporting, around 35,000m$^3$ of D+ Grade sawlogs were extracted from the Thomson Catchment in 2004-05 *[55]*. However, consumption hardwood sawn timber in Victoria, particularly in the building market, has declined by more than 50% since 2000 *[88]*. This is, in part, due to hardwood sawn timber products being displaced by plantation softwood sawn timber products *[89]*.

The case for continued logging in the Thomson Catchment on the basis of declining hardwood sawn timber demand needs to be costed against the increasing demand for water, particularly when supply of the water is decreasing. For example, the 2017-18 inflows of 413,000 ML to Melbourne's four major reservoirs, including the Thomson, were 33% below the long-term annual average for the period (1913-14 to 1996-97) and 16% below the average for the last 30 years *[37]*. Successive years have followed this trend *[90]*. In contrast, water demand has been increasing since 2010, with up to 449,000 ML of water being supplied in 2017-18, 5% more than the previous year *[37]*. Therefore, a possible set of policy options is to remove logging from the Thomson Catchment and replace native timber with feedstock sourced from plantations. This would increase water supply to the reservoir and promote expansion of the processing component of the plantation sector. The employment lost from the native forest sector would be more than compensated for by employment in the plantation processing sector. Indeed, a detailed trade-off analysis by Keith et al *[20]* suggests that such actions would generate a net positive economic benefit for the State of Victoria.

In summary, we have provided an analysis of a case study documenting competition for a key natural resource – water for regenerating trees following logging versus water for human consumption. Our analyses highlight the value of spatial analysis linked with hydrological relationships to generate future water yield projections as well as past changes to water yields as a consequence of past management actions. Water security in major urban areas is of increasing concern, as highlighted in recent media over water supply for cities such as Cape Town *[91,92]*. Guaranteeing water quality and water quantity demand long-term planning for infrastructure and the maintenance of water catchment integrity *[26]*. The work we have reported here demonstrates the need to maintain the integrity of forest cover in a key water supply catchment for the city of Melbourne by excluding native forest logging.

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