



## How Forests Regulate Streamflows

### NEFA BACKGROUND PAPER

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Prepared by: Dailan Pugh, 2014

Forests are responsible for capturing water from the atmosphere by increasing rainfall and condensing fog. This effect is enhanced by the taller trees and rougher canopy of an oldgrowth forest. Forests are also responsible for returning significant amounts of water to the atmosphere through transpiration, thereby contributing to rainfalls elsewhere.

Of the rain that falls upon a forested catchment some is evaporated directly from leaf and ground surfaces and part may be redirected by surface flows directly into streams. Except in intense rainfall events, the majority can be expected to infiltrate the soil where it is used for transpiration by plants, with the excess contributing to groundwater seepage into streams or possibly seeping deep down to aquifers. In a natural forest situation most of the streamflow response to rainfall is provided by the groundwater system.

Mackey *et. al.* (2010) identify that native vegetation has a multitude of effects in catchments:

*Various studies have also found that the presence of native vegetation can influence local rainfall in complex and unexpected ways and that land clearing can lead to a reduction in rainfall (Lyons et al 1993; Lyons 2002; Durieuxa et al 2003; Silberstein et al 2004; Gero and Pitman 2006; Preston and Jones 2006; Ray et al 2006). Native vegetation protection and rehabilitation are also important to other aspects of the hydrological cycle, including groundwater recharge, managing dryland salinity and maintaining riparian vegetation (Hairsine 1997).*

The identification of a relationship between forests, rainfall and water yields has long been recognised. Andreassian (2004) cites Pliny the Elder as probably the first to allude to the hydrological role of forests in his Natural History (written in the first century AD);

*Often, after woods have been cut down, springs on which trees used to feed emerge: for example, on mount Himus, when Cassander besieged the Gauls, who cut down a forest to build themselves an entrenchment. Often, disastrous torrents are formed after the felling of mountain woods, which used to hold back clouds and feed on them"*

Andreassian (2004) cites Bernardin de Saint Pierre *Studies of Nature* 'Etudes de la Nature' published between 1784 and 1788, describing the impact of forests on rain and streamflow in Mauritius:

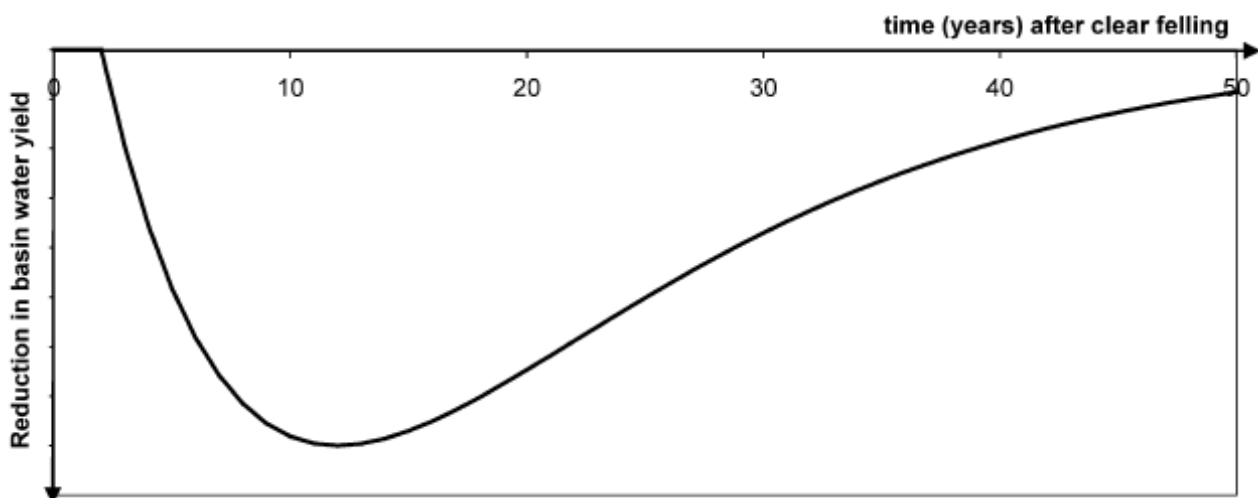
*This attractive force of the forests on this island is such that a field in an uncovered situation close to them often suffers a lack of rain whereas it rains almost all year long in woods that are situated within gunshot. It is by destroying part of the trees crowning the heights of this island that one has caused most of the streams that watered it to dry up. I attribute to the same lack of foresight the notable diminishing of the streams and rivers in a large part of Europe."*

Dargavel *et. al* (1995) note:

*Streamflow is the residue of rainfall after allowing for evaporation from vegetation, changes in soil storage from year to year and deep drainage to aquifers. Forest management operations can interfere with these processes by:*

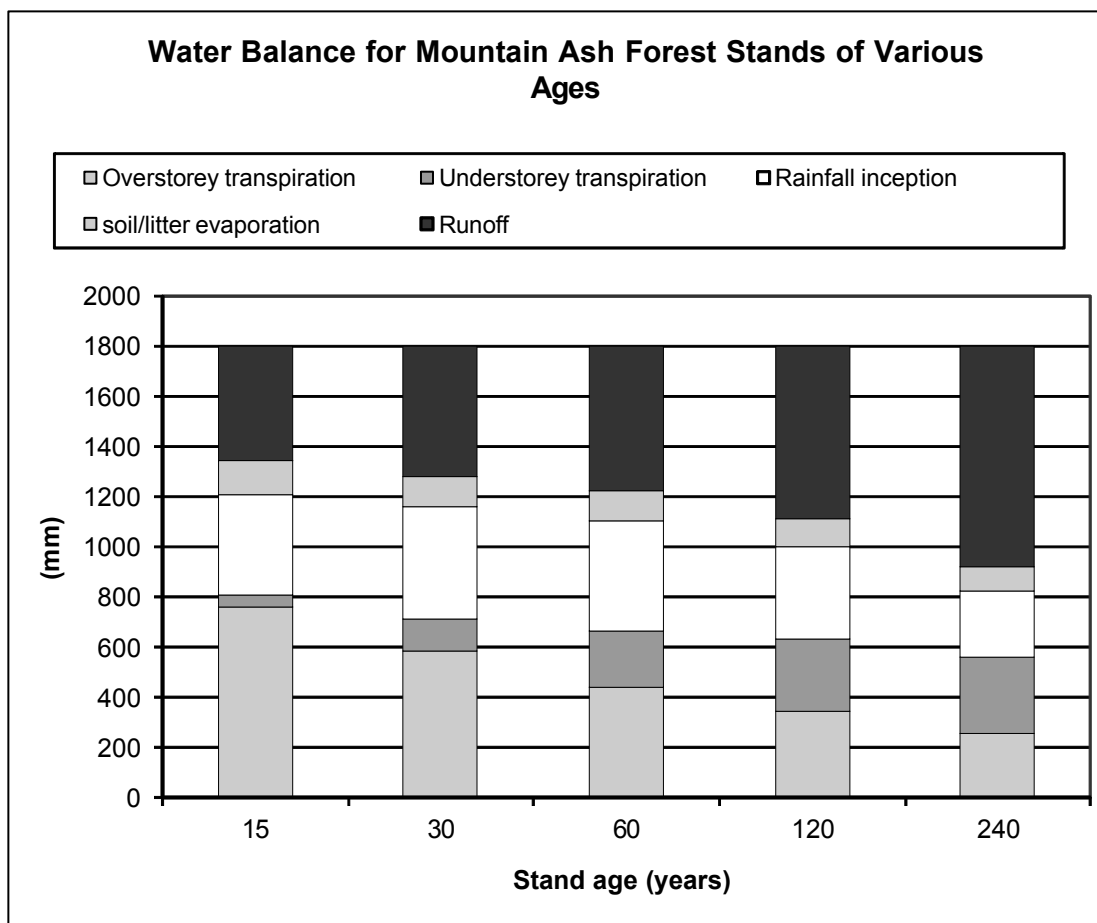
- *changing the type of vegetative cover on a catchment. Experimental results show that these changes can affect evapotranspiration and therefore streamflow;*
- *changing the soil properties. The ability of the soil to both absorb and store moisture infiltration can affect the proportion of rainfall delivered. Forest operations which compact the soil can reduce both infiltration and storage capacities.*

The most significant relationship between water yields and vegetation is that related to forest age. The basic relationship between water yields and eucalypt forest age was established by studies of regrowth Mountain Ash forests following wildfires in Victoria. Kuczera (1985, cited in Vertessy *et. al.* 1998) developed an idealised curve describing the relationship between mean annual streamflow and forest age for mountain ash forest. This shows that after burning and regeneration the mean annual runoff reduces rapidly by more than 50% after which runoff slowly increases along with forest age, taking some 150 years to fully recover.



Kuczera (1985) Curve.

Vertessy *et. al.* (1998) have attempted to quantify the different components of rainfall lost by evapo-transpiration, identifying them as: interception by the forest canopy and then evaporated back into the atmosphere; evaporation from leaf litter and soil surfaces; transpiration by overstorey vegetation; and transpiration by understorey vegetation. All of these have been measured as declining with increasing forest maturity, with the exception of understorey transpiration which becomes more important as transpiration from the emergent eucalypts declines.



*Water balance for Mountain Ash forest stands of various ages, assuming annual rainfall of 1800 mm (after Vertessy et. al. 1998)*

While not apparent at the large catchment scale used to generate the Kuczera curve, smaller catchments have been found to often generate increased flows of water following clearfelling where a significant area of the catchment is cleared. This “initial yield increase” is largely due to removal of vegetation and soil disturbance causing increased overland flows during rainfall events.

The generalised pattern following heavy and extensive logging of an oldgrowth forest is for there to be an initial increase in runoff peaking after 1 or 2 years and persisting for a few years. Water yields then begin to decline below that of the oldgrowth as the regrowth uses more water. Water yields are likely to reach a minimum after 2 or 3 decades before slowly increasing towards pre-logging levels in line with forest maturity.

For Mountain Ash forest in Victoria, a mean annual rainfall of 1,800 mm/yr has been found to generate a mean annual runoff from oldgrowth Mountain Ash forest of about 1,200 mm/yr (Kuzcera 1987, Vertessy et. al. 1998). After burning and regeneration the mean annual runoff reduces rapidly by more than 50% to 580 mm/yr by age 27 years, after which runoff slowly increases along with forest age, taking some 150 years to fully recover (Kuzcera 1987). Following clearfelling of a forest there may or may not be an initial increase in water yields for a relatively limited period. Thereafter water yields usually decline relatively rapidly in relation to growth indices of the regrowth, after some decades maximum transpiration of the regrowth is reached and water yields begin to recover with increasing forest maturity.

In the Barrington Tops area Cornish (1993) found that “*water yield decline exceeded 250 mm in the sixth year after logging in the catchment with the highest stocking of regeneration and the highest regrowth basal area*”. This represents a major reduction given that the mean runoff pre-logging was only 362 mm (38-678 mm) and that only 61% of its catchment was logged.

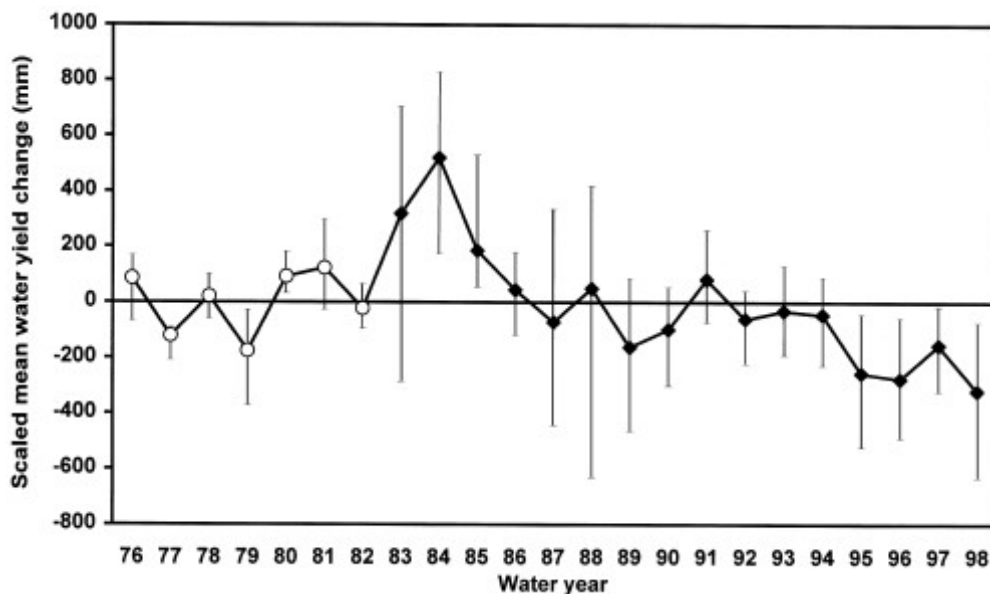
Cornish and Vertessy (2001) report that the yields kept declining:

*Water yields in a regrowth eucalypt forest were found to increase initially and then to decline below pre-treatment levels during the 16-year period which followed the logging of a moist old-growth eucalypt forest in Eastern Australia. ... Yield reductions of up to a maximum 600 mm per year in logged and regenerated areas were in accord with water yield reductions observed in Mountain Ash (*Eucalyptus regnans* F.J. Muell.) regeneration in Victoria. This study therefore represents the first confirmation of these Maroondah Mountain Ash results in another forest type that has also undergone eucalypt-to-eucalypt succession. Baseflow analysis indicated that baseflow and stormflow both increased after logging, with stormflow increases dominant in catchments with shallower soils. The lower runoff observed when the regenerating forest was aged 13–16 years was principally a consequence of lower baseflow.*

Cornish and Vertessy (2001) elaborate:

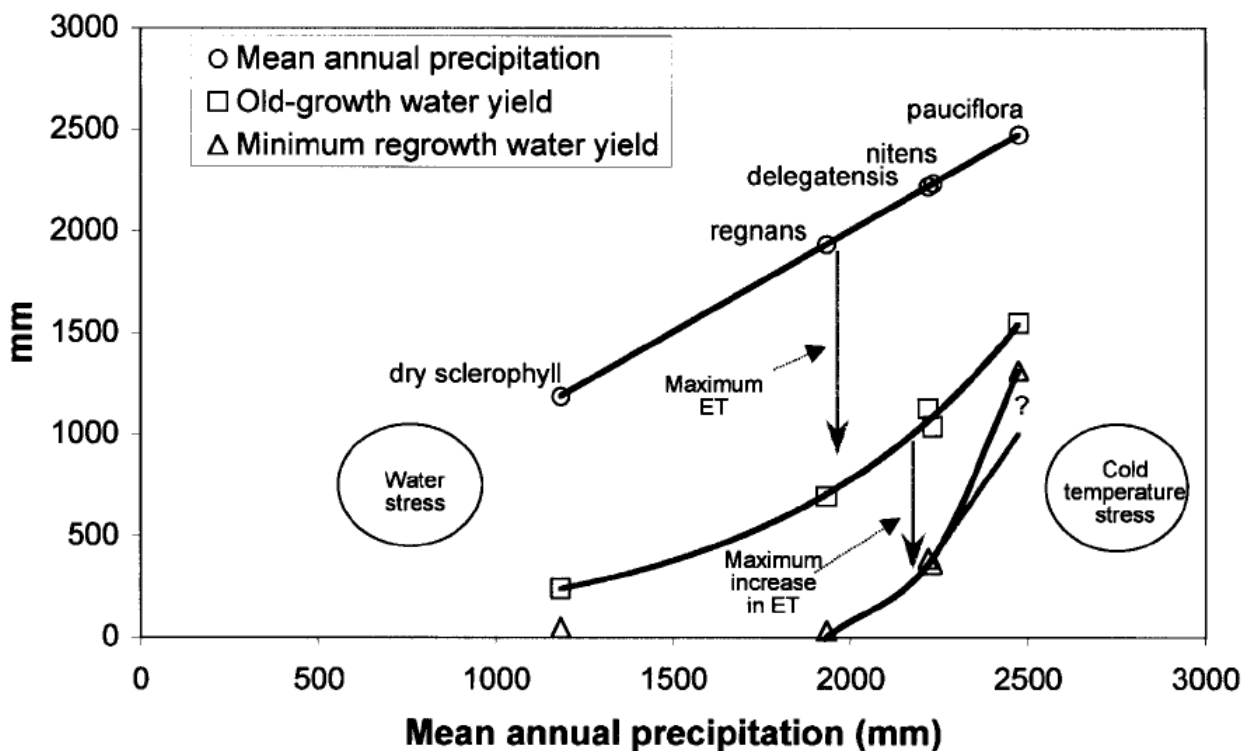
*This analysis indicates that (in common with the results of many previous studies, e.g. Bosch and Hewlett, 1982) canopy removal increased water yield substantially. Mean increases here were frequently significant while the regrowth trees were less than 3 years old. As the trees increased in age water use increased, but mean water use was not significantly different from the pre-treatment forest between ages 3 and 12. Water yields then declined further between ages 13 and 16 years, resulting in mean reductions being statistically significant in all but one catchment.*

Vertessy (1999) notes that “the maximum decrease in annual streamflow is over 60 mm per 10% of forest area treated, which is similar to the maximum reductions noted for Victorian mountain ash forests”.



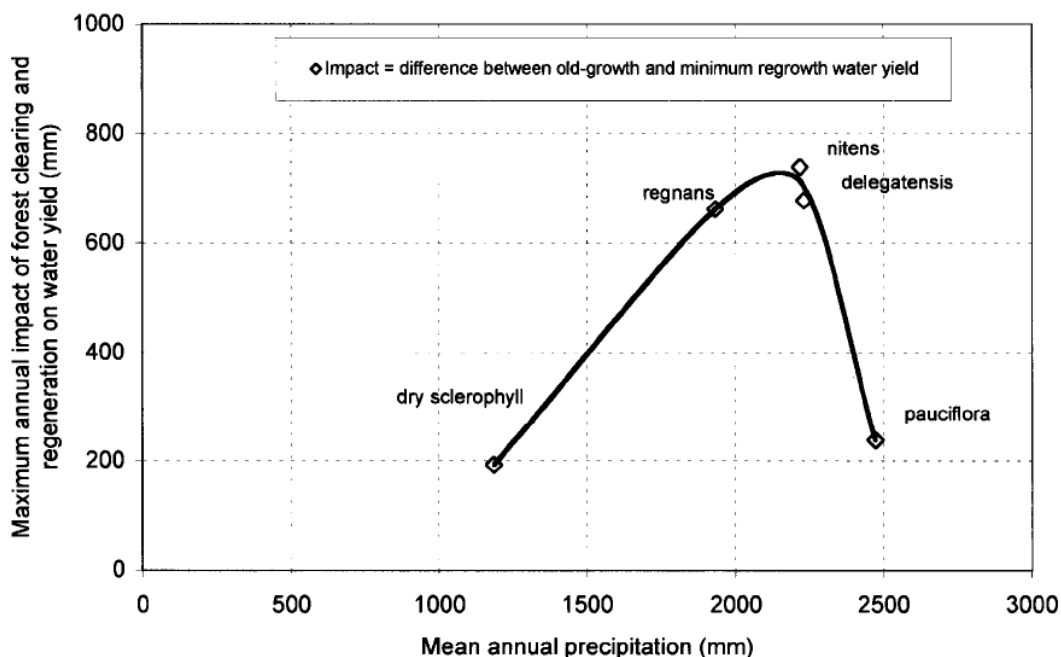
Means and ranges of estimated annual changes in water yield in the six Karuah research catchments logged (Cornish and Vertessy 2001).

Peel *et. al.* (2000) undertook modelling in the Maroondah and Thomson catchments to identify the variations in water yield depressions according to forest types and rainfall.



Summary of simulated impacts of forest clearing and regeneration on water yield, showing the relationship between species, precipitation, and water yields. From Peel *et. al.* (2000)

To make it more confusing, this relatively simple pattern is complicated by varying vegetation types and conditions within a catchment, the depth of soils, rainfall and a multitude of environmental variables, and the compounding effects of events over time. Even then we are still dealing with averages and it is in the drought events when water stored in dams and soils is of highest value, that impacts are greatly accentuated and have the most effect.



Relationship between species, precipitation and maximum impact of regeneration on water yields. From Peel *et. al.* (2000)

The effects of yield reductions are most pronounced in dry periods as the vegetation utilises proportionately more of the rainfall. Vertessy (1999) notes that South African studies demonstrated *“that absolute reductions in streamflow were greatest during the wet months, but that the reductions were proportionally greatest during the low flow periods”*.

Forest areas that have been recently logged or where regrowth is the dominant vegetation have a very rapid response time in relation to delivery of water into the storage system. Conversely, older less disturbed forests allow more water to permeate into the soil. Soil moisture then percolates more slowly through the catchment increasing the persistence of higher flows.

Water yield has been found not to return to pre-logging levels for some 150-200 years (Kuzcera 1987, O'Shanghnessy and Jayasuriya 1987).

SKM (2007) undertook modelling of the effects of the 2003 wildfires over the whole burnt area of Victoria and selected parts of NSW that drain into the River Murray or Victoria, and their initiation of regrowth, on water yields, identifying that in the absence of fire *“there would have been a net increase in streamflow over the next 150 years due to the natural aging of the forest”*, and concluding:

*The results indicate that the typical streamflow response following a fire consists of an initial increase followed by a long-term reduction, rejoining the streamflow response for a no-fire scenario after approximately 100 years. The initial increase in streamflow, compared to mean annual flow pre 2003, for the River Murray was predicted to be 1,116 GL and 250 GL for the Gippsland Lakes. The maximum reduction in streamflow for the Best Estimate was 692 GL for the River Murray by 2022 and 155 GL for the Gippsland Lakes by 2024, compared to mean annual flow pre 2003. However, compared to anticipated streamflow assuming no fire had occurred, streamflow under the Best Estimate fire scenario was 859 GL less for the River Murray and 195 GL less for Gippsland Lakes, both occurring by 2027.*

In their review of 'Logging and Water' Dargavel et. al. (1995) concluded *“The hydrological evidence reviewed in this report indicates that current logging regimes in the native forests of eastern Australia result in a decline in water yields. ... In catchments used to supply urban centres, this means that there is less water flowing into dams that provide water to cities and towns for drinking, washing, cleaning, watering gardens and industrial uses.”*

Dargavel et. al. (1995) note *“There are very large costs associated with providing water storage for urban water supply, so that decrease in stream flow may mean that greater or earlier investments in dams become necessary. Similarly, increased siltation of streams due to upstream economic activities may require dredging of dams or construction of new ones before they are due. These both impose costs on urban water consumers. Sediment from logging activities can increase the cost of municipal water treatment.”*

Water has an economic value that depends on its end use, being greatest in catchments supplying dams used for domestic water.

The major economic study of forests and water was carried out by Read Sturgess for Melbourne Water. Read, Sturges and Associates (1992) determined that the economic worth of water and timber from the forests of the Thomson Dam catchment, in Victoria, was maximised by either no logging at all or by strip thinning combined with a rotation length of 200 years. These two options had a 'Net Present Value' of \$147 and \$169 million, respectively, above continued logging under the current system.

Pugh (2000) undertook an assessment of the costs and benefits of protecting the then Whian Whian State Forest which encompasses part of the catchment of the Rocky Creek Dam, which is a regional water supply. He identified:

*State Forests (Cornish 1997) have conservatively estimated that logging has to date resulted in an overall reduction of 15-23% (5,600 to 8,400 megalitres - ML) in water yields to Rocky Creek Dam from the catchment. Though the actual reduction may in fact be as high as 16,800 ML .... If logging was now stopped in the whole catchment then its water yield will increase over time in line with forest maturity, with something like a third (1,900*

*ML to 5,600 ML) of the lost yields recoverable within the next 30 years and two thirds (3,700 ML to 11,100 ML) within 60 years.*

...

*The economic valuation of the water foregone due to continued logging of 30% of the catchment is likely to have a value of at least \$124,000 to \$366,000 per annum. Though if the benefits of delaying new infrastructure requirements are accounted for the Net Present Value (NPV) of ceasing logging in the remaining 30% of the catchment may be somewhere between \$2.5 and \$9.3 million.*

The North East Forest Alliance (2002) undertook water yield modelling to estimate how much additional water would be available if logging is excluded from the entire Central Coast catchment which is then regenerated back to an oldgrowth condition. 17,922 ha of State Forest (60%) was available for logging in the catchment, and 12,036 ha (40%) was 'unloggable'. NEFA concluded that there is a very high likelihood that the yields produced as a result of ending logging in the catchment will be in the order of 15 GL/annum.

It is evident that logging has significant impacts on water yields from native forests, such that:

- a. Reduction of mature and oldgrowth forest to younger growth stages will cause a significant reduction in water yields;
- b. Water yields will increase with increasing forest maturity; and,
- c. Logging should be excluded from significant water catchments.

**Stream health  
The Battle to Protect Soils and Streams  
Logging impacts on streams  
The Need for Stream Buffers  
Protecting Streams**

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