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Draft NSW Water Strategy

What is missing from the strategy is any consideration of the role of vegetation in generating rainfall and regulating streamflows. Through its structure and the process of evapotranspiration forests significantly influence regional rainfalls: initiating rainfall by causing clouds to rise, slowing winds, and their emission of rain condensation nuclei; condensing cloud moisture; drawing in moist air; and recycling rainfall back into the atmosphere through evapotranspiration. Forests store water in their soils and release it over time into streams. Forests play a key role in the water cycle and must be duly accounted for in any catchment strategy, particularly as changes in its extent and structure at a catchment scale will have a significant impact.

The structure of forest significantly affects the volume and persistence of water run-off into streams, therefore the strategy needs to map and account for forest structure and plantations in determining catchment water balance, current yields and future yields.

The headwaters of our rivers are vital to their health as this is where most of the interaction between the land and waters occurs. The retention of undisturbed buffers around streams is essential to trap sediments from entering waters, stabilise stream banks, shade waters, provide food and other resources to the aquatic environment, and maintain riparian habitat. The scientific evidence (Hansen *et. al.* 2010) is that stream buffers should be at least 30m wide and implemented around the saturated zone to maintain water quality and stream health. The protection and restoration of riparian buffers has to be the key focus of any strategy to improve water quality and aquatic habitats.

The 0-5m buffers applied to headwater streams in public and private logging operations in NSW are patently grossly inadequate to mitigate logging impacts on streams and have no scientific basis. They are therefore a major threat to riparian vegetation and the health of our waterways and their inhabitants, and must urgently be expanded to provide adequate protection.

CONTENTS:

1. Deliver and manage water for local communities Improve water security, water quality and flood management for regional towns and communities.

What is missing from the strategy is any consideration of the role of vegetation in generating rainfall and regulating streamflows. Through its structure and the process of evapotranspiration forests significantly influence regional rainfalls: initiating rainfall by causing clouds to rise, slowing winds, and their emission of rain condensation nuclei; condensing cloud moisture; drawing in moist air; and recycling rainfall back into the atmosphere through evapotranspiration. Forests store water in their soils and release it over time into streams. Forests play a key role in the water cycle and must be duly accounted for in any catchment strategy, particularly changes in its extent and structure at a catchment scale will have a significant impact.

Vegetation plays a significant role in climatic processes, from creating microclimates beneath their canopies, to modifying regional winds and temperatures, to enhancing rainfall, and changing atmospheric heat and moisture fluxes at continental scales. There is now abundant evidence that deforestation is having a significant impact on regional climates, and the reasons for this are becoming increasingly apparent.

Far from being passive, vegetation plays an active role in its partnership with climate (Zeng and Neelin 2000). Across the semi-arid Sahel in central Africa, the forests and woodlands of southern Australia, and the mighty Amazon rainforests, clearing, logging and burning of natural vegetation is causing a considerable increase in temperatures, decrease in evapotranspiration and decrease in rainfalls. As observed by Fu (2003):

> *Both the observational and theoretical studies have proved that the destruction of natural vegetation cover, such as destructive lumbering of forests and over cultivation and overgrazing of grassland has been one of the major causes for the deterioration of regional climate and environment.*

At the site level, compared to cleared areas, it is apparent that forests can create their own microclimate, with more stable temperatures (warmer on cold winter nights and cooler on hot days), and with moister soils and higher humidity in dry times (Meher-Homji 1991). Vegetation, and particularly forests, can affect regional climates by:

- transpiring moisture from the ground into the atmosphere to form clouds and generate rainfall
- providing a large area of leaves and other surfaces for evaporation of moisture back into the atmosphere
- creating areas of low pressure by evapotranspiration that generate winds and draw in moisture from afar
- having an 'evaporative cooling' effect by absorbing solar energy and converting it into latent heat held in water vapour through evapotranspiration
- emission of organic aerosols, and volatile organic compounds that oxidise to form aerosols, that act as cloud condensation nuclei around which water drops form

- increasing air turbulence, causing drag on the air and reducing wind speed, increasing transfer of moisture into the air, causing updrafts and rain
- tree canopies harvesting water directly from wind and clouds, particularly in coastal and mountainous country.

The influence of vegetation is related to many variables; the prevailing climate, the vegetation type and structure, its extent, the season and time of day. It is forests. with their large canopy volume, massive evapotranspiration, deep roots and protected microclimate that are the most significant terrestrial drivers of regional climates.

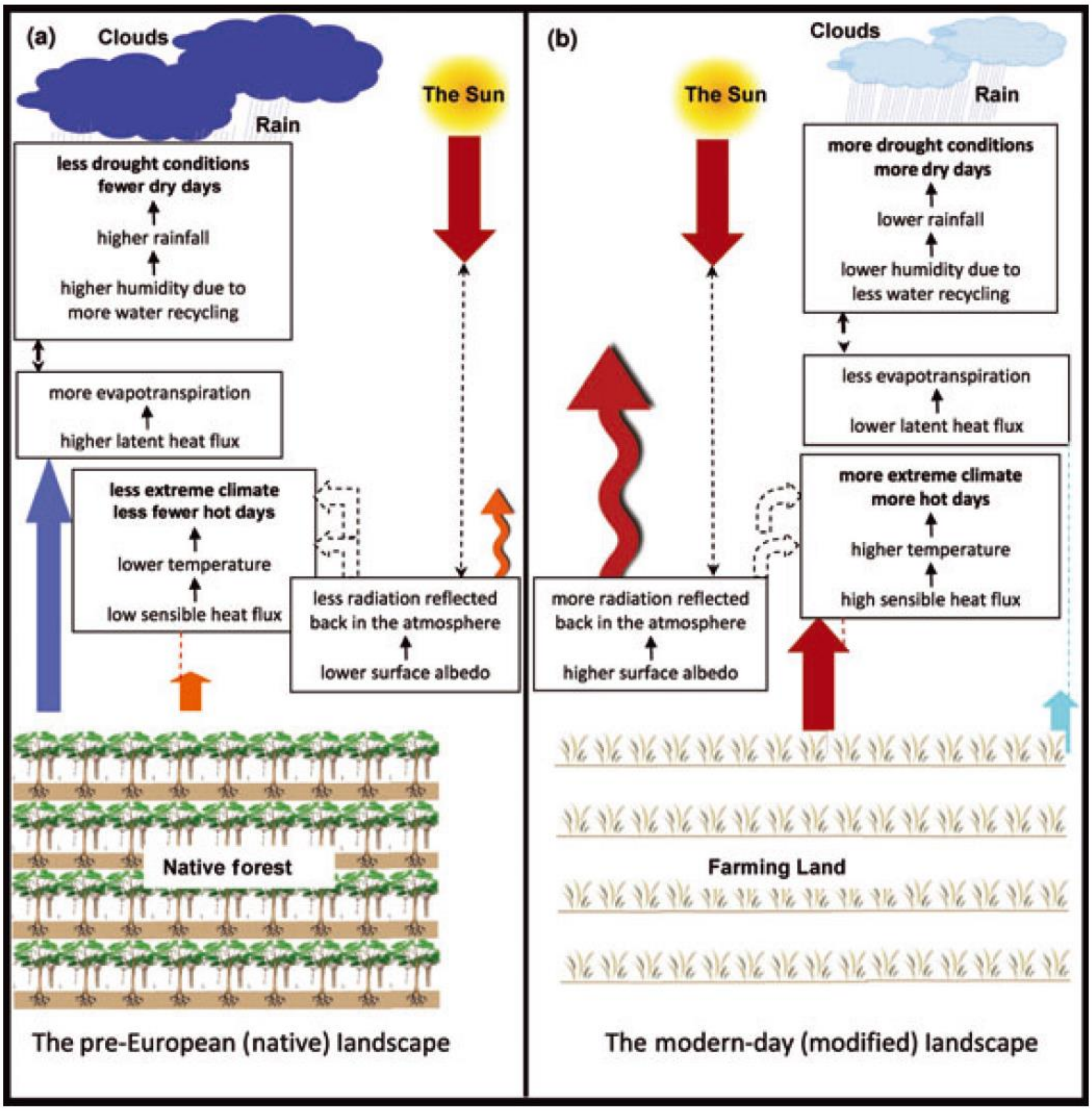


Figure 3 from Deo (2011). The impact of vegetation-cover change on surface energy balance, hydrological cycle and climate for two hypothetical landscapes: (a) pre-European (native) landscape, and (b) modern-day (modified) landscape. The coloured arrows show various energy/heat fluxes and black arrows show consequence of events or processes

Clearing vegetation can reduce rainfall by:

- reducing evapotranspiration and atmospheric moisture, causing a decrease in convective updrafts, clouds and the drawing in of moist air from afar;
- potentially increasing albedo (reflection of solar energy from the earth), having a cooling effect and causing a decrease in convective clouds;

- increasing runoff and reducing the availability of soil moisture for evapotranspiration;
- reducing rooting depth and the ability of vegetation to tap into, and recycle, groundwater;
- reducing vegetation height and surface roughness, increasing wind speed while reducing the ability of wind to capture moisture from canopies and the generation of updrafts;
- increasing surface sensible heat fluxes and decreasing latent heat fluxes, resulting is a reduction in evaporative cooling and raising the surface air temperature, causing drying; and,
- reducing organic aerosols and volatile organic compounds, and thus the availability of cloud condensation nuclei.

The regional impacts of deforestation can be amplified during drought conditions (i.e. Bagley 2011, Pitman *et. al.* 2012).

The thinning of native vegetation, including by burning and grazing, can have proportional impacts similar to clearing.

The conversion of forests to regrowth has a distinctly different impact as the regrowth increases transpiration of soil moisture to the atmosphere, which reduces runoff and theoretically increases atmospheric moisture. Though logging also changes the structure of the forest (reducing its surface roughness and rooting depth) as well as causing changes in energy balances and the interior microclimate, all of which would have negative impacts on rainfall. While the effect of regrowth on runoff has been extensively studied (see section 1.2), no study of the effect of regrowth on regional rainfalls was located, though experience in south-west Western Australia shows that when combined with declining rainfalls, the increased transpiration of regrowth can have disastrous consequences for regional water supplies and the health of the forest.

The complex feedback systems contributing to rainfall can come under increasing stress due to the degradation of vegetation, sometimes resulting in sudden catastrophic changes when an event triggers regime shifts. McAlpine *et. al.* (2009) consider:

> *Climate changes due to increased anthropogenic greenhouse gases coupled with land surface feedbacks appears to be amplifying the natural climate variability and has the potential to tip Australia's climate, especially in southeast Australia, into a new regime of more extensive, frequent and severe droughts. The term 'tipping' refers to a critical threshold at which a small change in the control parameters can alter the state of the climate system*

Excessive clearing has been associated with the downfall of many past civilisations. We need to learn from the lessons of history, understand and acknowledge the consequences of deforestation, and stop the desertification of Australia.

1.1. Evapotranspiration

The atmosphere receives vast inputs of water vapour as evaporation from the oceans and land, as well as transpiration by vegetation. This water vapour is returned to earth as rainfall, with the water in the atmosphere turned over about 34 times every year.

Evapotranspiration is used to account for the evaporation of water from the ground and wet vegetation, along with the conversion of water to vapour through the process of transpiration by plants. Transpiration involves the transport of water (and nutrients) from roots to leaves, where it is released by evaporation to the atmosphere through stomata on leaves.

By one estimation, evapotranspiration across the global land surface (excluding water bodies and permanent ice surfaces) is 63,200 km^3yr^{-1}, which is 67% of mean annual rainfall (Zhang *et. al.* 2016), with the balance being transported back to the oceans by rivers, or diverted into deep aquifers. Transpiration by plants is responsible for recycling huge volumes of water and thus significantly contributes to atmospheric moisture, clouds and resultant rainfall. Transpiration is considered to be responsible for around 65% of evapotranspiration, evaporation from wet vegetation around 10%, and evaporation from the soil for around 25% (Zhang *et. al.* 2016). Miralles *et. al.* (2010) put the evaporation from forests as being higher, identifying that canopy interception of rainfall is responsible for the evaporation of approximately 13% of the total incoming rainfall over broadleaf evergreen forests, 19% in broadleaf deciduous forests, and 22% in needleleaf forests.

Van der Ent *et. al* (2010) consider that "*It is computed that, on average, 40% of the terrestrial precipitation originates from land evaporation and that 57% of all terrestrial evaporation returns as precipitation over land*". It has been found in the Amazon that evapotranspiration from forests accounts for more than 50% of rainfall (Nobre *et. al* 1991, Spracklen *et. al.* 2012)

The amount of water that can be recycled by evapotranspiration from vegetation is related to canopy volume (the area of leaves -Leaf Area Index) and root depth (the ability to access deeper water sources), thus it is tall forests with their large canopies and deep roots that provide the highest rate of evapotranspiration. When vegetation is cleared there is a reduction in surface area for evaporation, reduced transpiration, increased runoff and a reduced ability to access deeper soil moisture. By reducing evapotranspiration, deforestation results in less water being pumped into the atmosphere, thereby directly contributing to a decrease in rainfall (Shukla *et. al.* 1990, Nobre *et. al* 1991, Spracklen *et. al.* 2012, Andrich and Imberger 2013).

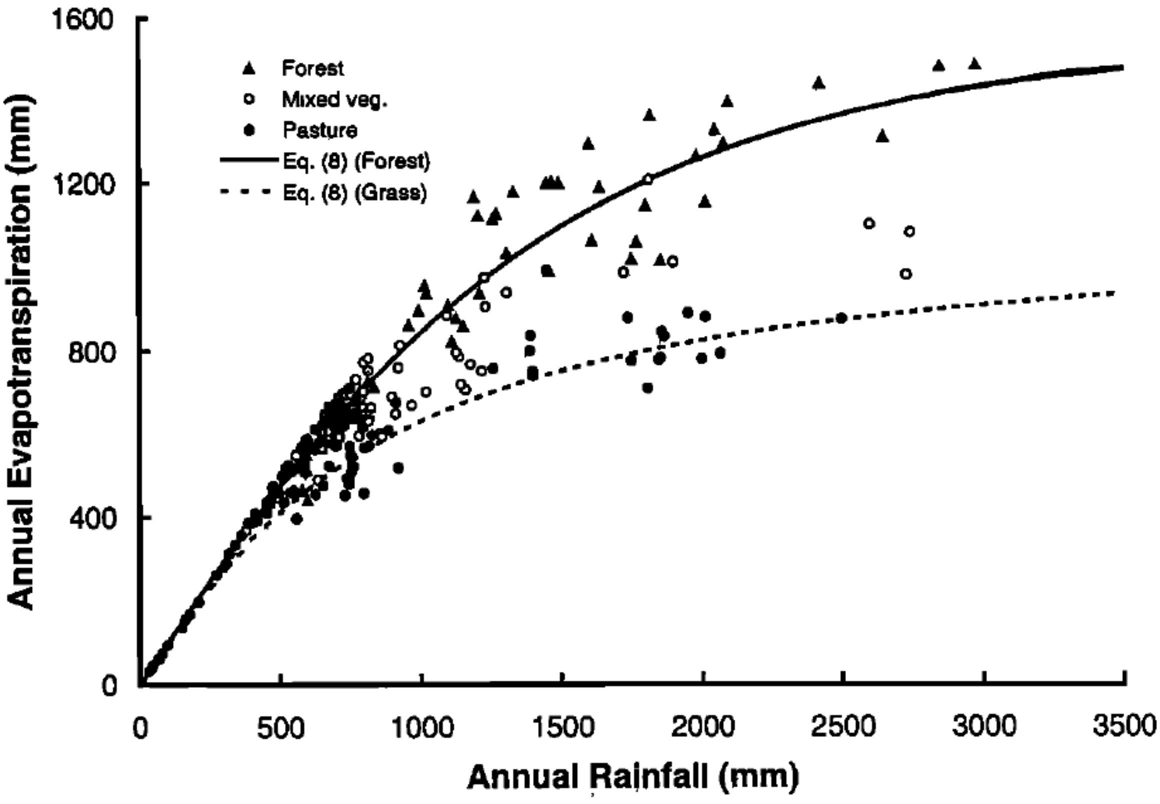


Figure 9 from Zang *et. al.* (2001): generalised relationship between annual evapotranspiration and rainfall for different vegetation types. The difference between the grass and forest curve represents the change in mean annual water yield for a 100% change in vegetation for a given mean annual rainfall.

In comparison to large canopied and deeply rooted woody vegetation, grasslands and crops only have small leaf areas and shallow rooting structures and thus lower evapotranspiration. They have less resources to tap in times of drought. Annual crops only transpire water during part of the year.

They do not capture as much rainfall and soil moisture as the native vegetation, meaning less water vapour is returned to the atmosphere to be available for precipitation.

From their comparison of Amazonian pasture and rainforest, von Randow *et. al.* (2004) found that in the wet season "*evapotranspiration rates are 20% lower in the pasture, compared to the forest",* and in the dry season evapotranspiration *"rates are 41% lower in the pasture".*

Zang *et. al.* (2001) consider that "*Under dry conditions the principal controls on evapotranspiration are plant-available water and canopy resistance. Under wet conditions the dominant controls are advection, net radiation, leaf area, and turbulent transport. Under intermediate conditions the relative importance of these factors varies depending on climate, soil, and vegetation*". Zang et. al. (2001) developed a generalised model for vegetation evapotranspiration, noting "*in spite of the complexity of the soil-vegetation-atmosphere system the most important factors controlling mean annual evapotranspiration appear to be annual rainfall, potential evapotranspiration, and vegetation type*".

Most of the rain that falls upon a forest is recycled to the atmosphere through evapotranspiration, where it again becomes available for rainfall. Water may be recycled numerous times as it passes over the land before it returns to the oceans in streamflows or as rainfall. This process is vital for maintaining rainfall over inland areas.

From their analyses of tropical land surface (latitudes 30 degrees south to 30 degrees north) Spracklen *et. al.* (2012) found that for more than 60 per cent of the land air that has passed over extensive vegetation in the preceding few days produces at least twice as much rain as air that has passed over little vegetation. noting:

> *... additional moisture from evapotranspiration emitted into air masses with large exposure to vegetation is substantially greater than the additional precipitation observed in these air masses. Indeed, for all four regions the extra* [cumulative surface evaporation] *emitted into air masses with large vegetation exposure exceeds the observed additional precipitation by a factor of at least four...*
>
> *Through evapotranspiration, forests maintain atmospheric moisture that can return to land as rainfall downwind. These processes operate on timescales of days over distances of 100–1,000km ...such that large-scale land-use change may alter precipitation hundreds to thousands of kilometres from the region of vegetation change.*

In the central Amazon basin over half of the precipitated water goes back into the atmosphere through evapotranspiration, while approximately 45 percent are drained by rivers back to the ocean (Tavares 2012). Moisture-laden winds from the Atlantic Ocean account for 52 percent of the rainfall, with the balance recycled by the vegetation (Tavares 2012).

Nobre *et. al* (1991) identify that the main source of water vapour to the Amazon is the Atlantic Ocean, though in western Amazonia 2,000-3,000 km inland the water column apparently has more water vapour than near the Atlantic coast, commenting "*recycling of water vapor through evapotranspiration is clearly very important*".

Van der Ent *et. al* (2010) identify that local moisture recycling is a feature of some regions, though in most regions the majority of rainfall originates from elsewhere, for example:

> *Moisture evaporating from the Eurasian continent is responsible for 80% of China's water resources. In South America, the Río de la Plata basin depends on evaporation from the Amazon forest for 70% of its water resources. The main source of rainfall in the Congo basin is moisture evaporated over East Africa, particularly the Great Lakes region. The Congo basin in its turn is a major source of moisture for rainfall in the Sahel*.

It is important to consider that clearing forests in one region can have significant adverse impacts on rainfall in another region. Van der Ent *et. al.* (2010) consider:

> *Our results suggest that decreasing evaporation in areas where continental evaporation recycling is high (e.g., by deforestation), would enhance droughts in downwind areas where overall precipitation amounts are low. On the other hand, water conservation in these areas would have a positive multiplier effect on rainfall downwind.*

Sheil and Murdiyarso (2009) consider:

> *The world's hydrological systems are changing rapidly. Food security in many regions is heavily threatened by changing rainfall patterns (Lobell et al. 2008). Meanwhile, deforestation has already reduced vapor flows derived from forests by almost five percent (an estimated 3000 cubic kilometers [km^3] per year of a global terrestrial derived total of 67,000 km^3), with little sign of slowing (Gordon et al. 2005). The need for understanding how vegetation cover influences climate has never been more urgent.*

1.1.1. Forests as Biotic Pumps

Bernardin de Saint Pierre (1784-8) was not alone in the 18th century with his observation "*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 has long been observed that vegetation attracts rainfall, rather than simply being a product of it. More recent studies have confirmed such observations, though the mechanisms are still poorly understood,

It is apparent that vegetation has an ability to attract rainfall to itself even in semi-arid environments. For their study area in central Africa, Los *et. al.* (2006) identified "*positive feedback between vegetation and rainfall at the monthly time scale, and for a vegetation memory operating at the annual time scale*", noting "*These vegetation-rainfall interactions increase the interannual variation in Sahelian precipitation; accounting for as much as 30% of the variability in annual precipitation in some hot spot regions*".

In the Kalahari of southern Africa Chikoore and Jury (2010) found a flush of vegetation resulting from a rain event *"'draws' airflow toward itself in a self-sustaining way"*, noting:

> *An increase in vegetation appears to draw the airflow toward itself, enhancing the low-level buoyancy and slowing the winds through friction, thereby causing convergence and uplift. Thus vegetation seems to impact horizontal momentum transfer as much as vertical moisture flux.*

A variety of studies in tropical environments have identified that rainfall can decline following deforestation by more than the reduction in evapotranspiration can account for, indicating that there is a reduction of moisture influxes into a region following deforestation. From their observations and modelling in the Amazon, Shukla *et. al.* (1990) concluded:

> *The reduction in calculated annual precipitation by 642 mm and in evapotranspiration by 496 mm suggests that changes in the atmospheric circulation may act to further reduce the convergence of moisture flux in the region ...*
>
> *... a reduction in evaporation might be compensated for by an increase in moisture flux convergence. Our experiments indicate that such a compensation will not occur for the Amazon and that there is even a further decrease in convergence of the large-scale moisture flux.*
>
> *...*
>
> *The most significant result of this study is the simulated reduction in precipitation over Amazonia, which is larger than the corresponding regional reduction in evapotranspiration,*

> *implying that the dynamical convergence of moisture flux also decreased as a result of deforestation.*

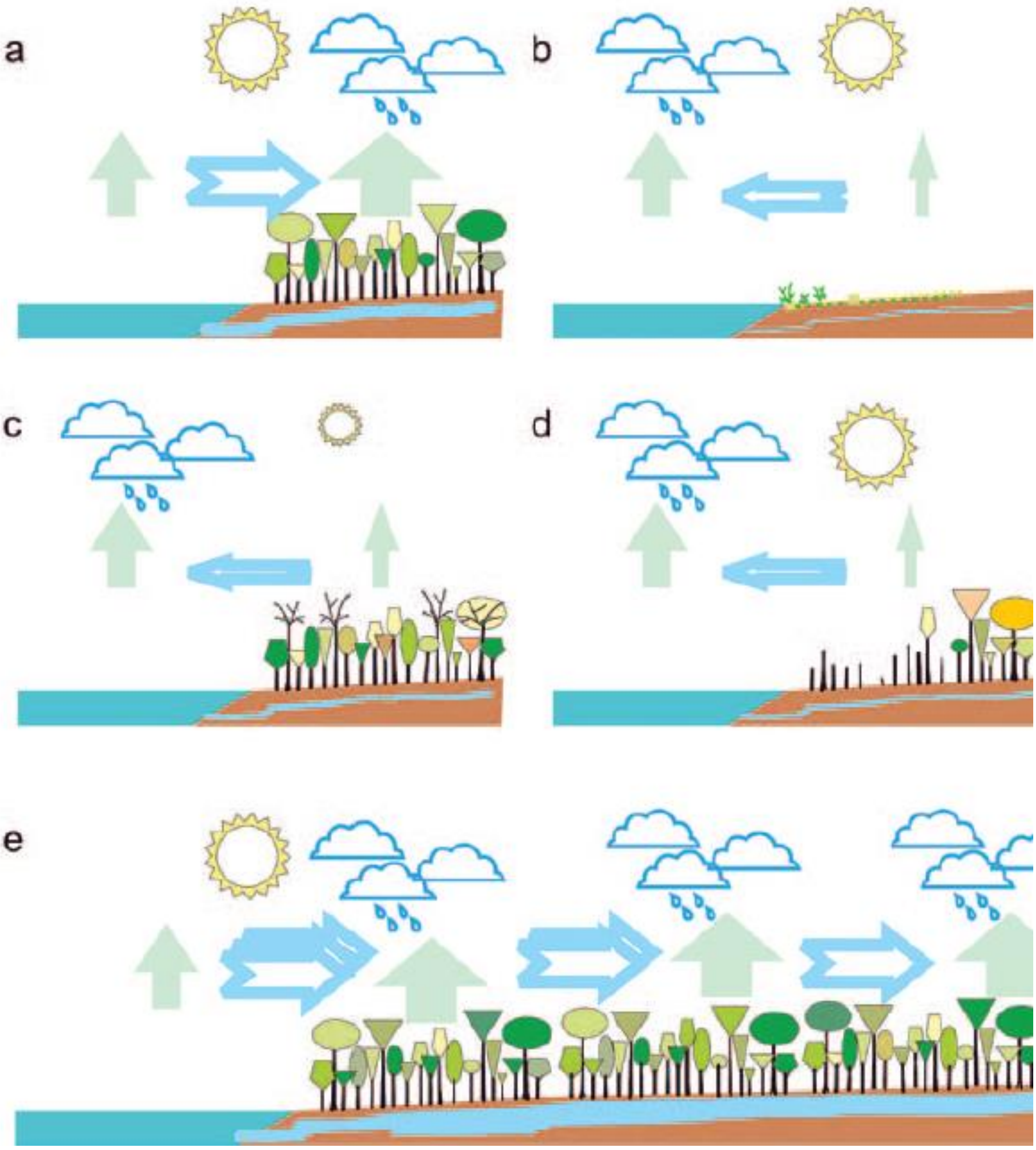
From their studies of the Amazon, Nobre *et. al* (1991) concluded "*The calculated reduction in precipitation was larger than the calculated decrease in evapotranspiration, indicating a reduction in the regional moisture convergence*".

In their modelling of the impact of conversion of savannas to grasslands, Hoffmann and Jackson (2000) found *"precipitation declined more than did evapotranspiration, indicating a reduction in moisture convergence (Table 2). Moisture convergence, that is, the net flux of water vapor into a region, has similarly been found to decline in most tropical deforestation simulations*".

It has been postulated that forests play a crucial role in hydrological cycles by acting as the Biotic Pump of atmospheric moisture (Makarieva and Gorshkov 2006, Makarieva *et. al.* 2009, Makarieva and Gorshkov 2010, Sheil and Murdiyarso 2009). From their study, Makarieva and Gorshkov (2006, 2009) concluded that the mean distance that the atmosphere can transport moisture inland over non-forested land does not exceed several hundred kilometers, with precipitation decreasing exponentially with distance from the ocean. They note that in contrast, precipitation over extensive natural forests does not depend on the distance from the ocean along several thousand kilometers.

Makarieva and Gorshkov (2006) found that areas with strong evaporation/transpiration draw in moisture from areas with low evaporation, thereby enhancing rainfall. Makarieva and Gorshkov (2006) postulated that natural forests are the biotic pump of atmospheric moisture:

> *Due to the high leaf area index, natural forests maintain powerful transpiration exceeding evaporation from the oceanic surface. The transpiration flux supports ascending fluxes of air and "sucks in" moist air from the ocean. In the result, forest precipitation increases up to a level when the runoff losses from optimally moistened soil are fully compensated at any distance from the ocean.*
>
> *Natural forest ecosystems, with their high leaf area index and high transpiration exceeding evaporation from open water surface, are capable of pumping atmospheric moisture from the ocean in amounts sufficient for the maintenance of optimal soil moisture stores, compensating the river runoff and ensuring maximum ecosystem productivity.*



An illustration of the biotic pump, from Sheil and Murdiyarso (2009): Atmospheric volume reduces at a higher rate over areas with more intensive evaporation solid vertical arrows, widths denotes relative flux). The resulting low pressure draws in additional moist air (open horizontal arrows) from areas with weaker evaporation. This leads to a net transfer of atmospheric moisture to the areas with the highest evaporation. (a) Under full sunshine, forests maintain higher evaporation than oceans and thus draw in moist ocean air. (b) In deserts, evaporation is low and air is drawn toward the oceans. (c) In seasonal climates, solar energy may be insufficient to maintain forest evaporation at rates higher than those over the oceans during a winter dry season, and the oceans draw air from the land. However, in summer, high forest evaporation rates are re-established (as in panel a). (d) With forest loss, the net evaporation over the land declines and may be insufficient to counterbalance that from the ocean: air will flow seaward and the land becomes arid and unable to sustain forests. (e) In wet continents, continuous forest cover maintaining high evaporation allows large amounts of moist air to be drawn in from the coast. Not shown in diagrams: dry air returns at higher altitudes, from wetter to drier regions, to complete the cycle, and internal recycling of rain contributes significantly to continental scale rainfall patterns. Source: Adapted from ideas presented in Makarieva and Gorshkov (2007).

A review of the Biotic Pump theory by Sheil and Murdiyarso (2009) concluded:

The underlying mechanism emphasizes the role of evaporation and condensation in generating atmospheric pressure differences, and accounts for several phenomena neglected by existing models. It suggests that even localized forest loss can sometimes flip a wet continent to arid conditions. If it survives scrutiny, this hypothesis will transform how we view forest loss, climate change, hydrology, and environmental services. It offers new lines of investigation in macroecology and landscape ecology, hydrology, forest restoration, and paleoclimates. It also provides a compelling new motivation for forest conservation.

...

Researchers have previously puzzled over a missing mechanism to account for observed precipitation patterns (Eltahir 1998). Makarieva and Gorshkov's hypothesis offers an elegant solution: they call it a "pump."

...

Conventional models typically predict a "moderate" 20 to 30 percent decline in rainfall after continental-scale deforestation (Bonan 2008). In contrast, Makarieva and Gorshkov suggest that even relatively localized clearing might ultimately switch entire continental climates from wet to arid, with rainfall declining by more than 95 percent in the interior.

For the biotic pump to provide more inland rainfall, vegetation transpiration fluxes need to exceed the fluxes of evaporation from the open water surface of the ocean. The strength and effectiveness of the biotic pump, and thus inland rainfall, is dependent on the number of trees in the forest and the area of the forest-cover. Makarieva and Gorshkov (2006) found that "*Replacement of the natural forest cover by a low leaf index vegetation leads to an up to tenfold reduction in mean continental precipitation and runoff*", also noting:

The biotic moisture pump, as well as the mechanisms of efficient soil moisture preservation ... work in undisturbed natural forests only. Natural forest represents a contiguous cover of tall trees that are rigidly associated with other biological species of the ecological community and genetically programmed to function in the particular geographic region. The vegetation cover of grasslands, shrublands, savannas, steppes, prairies, artificially thinned exploited forests, plantations, pastures or arable lands is unable to switch on the biotic moisture pump and maintain soil moisture content in a state optimal for life. Water cycle on such territories is critically dependent on the distance from the ocean; it is determined by random fluctuations and seasonal changes of rainfall brought from the ocean. Such territories are prone to droughts, floods and fires.

... If the natural forest cover is eliminated along the oceanic coastline on a band [around] *600 km wide, the biotic moisture pump stalls. The remaining inland forests are no longer able to pump atmospheric moisture from the ocean. There is no longer surplus to runoff to rivers or to recharge groundwater. ...*

...

The results obtained form the basis of a possible strategy to restore human-friendly water conditions on most part of the Earth's landmasses, including modern deserts and other arid zones. As we have shown, elimination of the forest cover in world's largest river basins would have the following consequences: at least one order of magnitude's decline of the river runoff, appearance of droughts, floods and fires, partial desertification of the coastal zone and complete desertification of the inner parts of the continents, ...associated economic losses would by far exceed the economic benefits of forest cutting ... Therefore, it is worthy to urgently reconsider the modern forest policy everywhere in the world. First of all, it is necessary to immediately stop any attempts of destroying the extant natural forest remnants and, in particular, those bordering with the ocean or inner seas. Further on, it is necessary to initiate a world-wide company on facilitating natural gradual recovery of aboriginal forest ecosystems on territories adjacent to the remaining natural forests. Only extensive *contiguous natural forests will be able to run a stable water cycle and subsequently intensify it, gradually extending the river basin at the expense of newly recovering territories.*

Makarieva and Gorshkov (2006) conclude:

> *Forests are responsible both for the initial accumulation of water on continents in the geological past and for the stable maintenance of the accumulated water stores in the subsequent periods of life existence on land. ... It is shown that only intact contiguous cover of natural forests having extensive borders with large water bodies (sea, ocean) is able to keep land moistened up to an optimal for life level everywhere on land, no matter how far from the ocean.*

1.1.2. Surface Roughness

The structure of vegetation has a significant impact on rainfall that is related to its height, leaf area density, and canopy roughness. Natural vegetation reduces wind speed through its aerodynamically rough, undulating canopy, causing turbulence and the mixing of air. Due to the decrease in wind velocity, the air masses are forced to stack and rise, which is enhanced by the height of the vegetation. This increases the influx of water vapour into the lower atmosphere, and thus promotes condensation and rainfall. As described by Bagley (2011):

> *Depending on whether surface roughness increases or decreases the change enhances or diminishes fluxes of water, energy, and momentum from the earth's surface to the atmospheric boundary layer through the enhancement or diminishment of eddy formation in the surface layer*

Just by their height trees can have an orographic effect (moist air rising over a physical barrier), as noted by Andrich and Imberger (2013) for Western Australia: "*Rainfall changes by ~40 mm for every 100 m in altitude between Fremantle and the hill reservoirs*". Cutting down trees thus reduces the "*surface boundary layer height*" and rainfall.

The decrease in surface roughness caused by deforestation reduces the transfer of energy to the atmosphere in the form of turbulent fluxes and thus rainfall. The low and even canopies of crops and grasslands reduce surface roughness, turbulent mixing in the boundary layer, evapotranspiration and thus rainfall. This is considered by many researchers to be a key contribution to the decrease in rainfall resultant from land cover change (Sud and Smith 1985, Shukla *et. al.* 1990, Nobre *et. al* 1991, Meher-Homji 1991, Claussen 1998, Sud *et. al.* 1998, Hoffmann and Jackson 2000, Foley *et. al.* 2003b, Pitman *et.al.* 2004, Sheil and Murdiyarso 2009, Findell *et. al.* 2007, Chapin III *et al*., 2008, Sheil and Murdiyarso 2009, Findell *et. al.* 2009, McAlpine *et. al.* 2009, Davin and de Noblet-Ducoudré 2010, Nair *et. al* 2011, Kala *et. al.* 2011, Deo 2011, Bagley 2011, de Noblet-Ducoudré *et. al.* 2012, Andrich and Imberger 2013, Chen and Dirmeyer 2016).

Sheil and Murdiyarso (2009) state:

> *Forest evaporation benefits from canopy height and roughness, which leads to turbulent airflows. This has been termed the "clothesline effect," as it is the same reason laundry dries more quickly on a line than when laid flat on the ground (Calder 2005). If moisture is sufficient, forest evaporation is constrained principally by solar radiation and weather (Calder et al. 1986, Savenije 2004). Large tropical trees can transpire several hundred litres of water each day (Goldstein et al.1998).*

An example of the aerodynamic effect on local precipitation has been studied in south-west Australia, where rainfall has reduced and river flows around the city of Perth have fallen by around 40% since the mid twentieth century. This decreasing trend has been attributed to deforestation (Adams 2010). The replacement of forests by cropland and pasture has reduced the aerodynamic roughness of the surface. After clearance of the forests, the rainfall occurs further inland and outside of the river catchments around Perth. An analysis of observations and regional model results by Nair et al. (2011) supports these ideas. The loss of the forest has resulted in reduced wintertime rainfall over the areas cleared, which is partly caused by the reduced aerodynamic roughness after conversion of forests to crops. A more heterogeneous pattern of forest and wheat could have helped to reduce the local change in rainfall (Chapin III *et al*., 2008).

Kala *et. al.* (2011) modelled a summer and a winter cold front in south-west WA to assess the impacts of land clearing, and:

> *found that land-cover change results in a decrease in precipitation for both fronts, with a higher decrease for the summer front. The decrease in precipitation is attributed to a decrease in turbulent kinetic energy and moisture flux convergence as well as a increase in wind speed within the lower boundary layer. The suggested mechanism is that the enhanced vertical mixing under pre-European vegetation cover, with the decrease in wind speeds close to the ground, enhance microphysical processes leading to increased convective precipitation. The higher decrease in precipitation for the summer front is most likely due to enhanced convection during summer.*

From their modelling of Monsoon rains over India, Sud and Smith (1985) concluded that "*the influence of surface roughness change is as important as that of surface albedo change*", identifying that "*small changes in wind magnitude or direction, can produce significant changes in the moisture convergence and rainfall*", and that "*the presence of tall vegetation over India would increase its July rainfall*". From their global modelling review, Sud *et. al.* (1998) considered that they showed "*that the surface roughness significantly influences the atmospheric circulation and precipitation, especially in the tropics, because it directly affects the boundary layer water vapor transport convergence*", concluding that the *"height of the earth's vegetation cover, which is the main determinant of surface roughness, has a large influence on the boundary layer water vapor transport convergence and the rainfall distribution*".

As well as decreasing rainfall, the reduction in surface roughness due to deforestation is considered to have a strong warming influence (Foley *et al*. 2003, Davin and de Noblet-Ducoudré 2010, Deo 2011, Chen and Dirmeyer 2016), Davin and de Noblet-Ducoudré (2010) noting "*reduced surface roughness leads to weaker turbulent exchanges. Since the energy available at the surface cannot be transferred to the atmosphere through turbulent fluxes, the surface tends to warm*"

Chen and Dirmeyer (2016) consider that surface roughness effects usually dominate the direct biogeophysical feedback of deforestation, while other effects play a secondary role, finding:.

> *Grasslands or croplands are aerodynamically smoother than forest and transfer heat less effectively, thus experiencing higher surface temperatures during daytime and lower surface temperatures at night*

Based on comparisons of surface temperature change from forest to open land at paired observation sites, Chen and Dirmeyer (2016) identified that in summer deforestation leads to an observed daytime warming (+2.23±0.94 K) and a cooling effect at night (−2.05±1.02 K), noting "*roughness change exhibits the largest impact (1.96+0.60 K during the day, −1.62+0.61 K at night)*".

Vegetation can also directly strip water from fog and clouds in mountainous areas and along coastal fog zones with significant affects on the water available for the forests, transpiration and streamflows (i.e. Lima 1984, Meher-Homji 1991, Hutley *et. al.* 1997, Foley et. al. 2003b, Sheil and Murdiyarso 2009). Meher-Homji (1991) note:

> *Even a single tree or a group of trees can trap a substantial quantity of rainwater through the process called horizontal precipitation .... The amount so trapped can vary from 7 to 18% of the rainy-season precipitation and up to 100% of dry-season rains .... The destruction of*

> *such cloud forests (as in the Western Ghats of India) can diminish stream flows and ground-water recharge.*

Hutley *et. al.* (1997) identify that numerous observers have considered that the occurrence of low cloud, fog and mist may be important to the survival of Australian rainforests at upland sites. They assessed a rainforest site on the Great Dividing Range west of Brisbane, finding that leaves were wet for 25% of the time solely from dew and fog events, with frequent wetting of the canopy reducing transpiration rates, and allowing the leaves to directly absorb liquid surface water. Hutley *et. al.* (1997) conclude:

> *Fog deposition to the forest provides the equivalent of an additional 40% of rainfall to the site as measured using a conventional rain gauge. A frequently wet canopy results in reduced transpiration rates and direct foliar absorption of moisture alleviates water deficits of the upper crown leaves and branches during the dry season. These features of this vegetation type may enable long-term survival at what could be considered to be a marginal rainforest site.*
>
> *...*
>
> *Near-coastal massifs, such as the Great Dividing Range in southern Queensland, will have an ability to intercept and deflect moist air, which will have a significant local impact on rainfall. The present study has demonstrated the importance of fog and cloud occurrence. This could also be true of upland sites along the entire Eastern Highlands of Australia and may be significant given the frequency of the occurrence of water deficits in Australian rainforests.*

1.2. The effects of forest structure on water yields to streams.

The structure of forest significantly affects the volume and persistence of water run-off into streams, therefore the strategy needs to map and account for forest structure and plantations in determining catchment water balance, current yields and future yields.

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.

The eWater CRC notes:

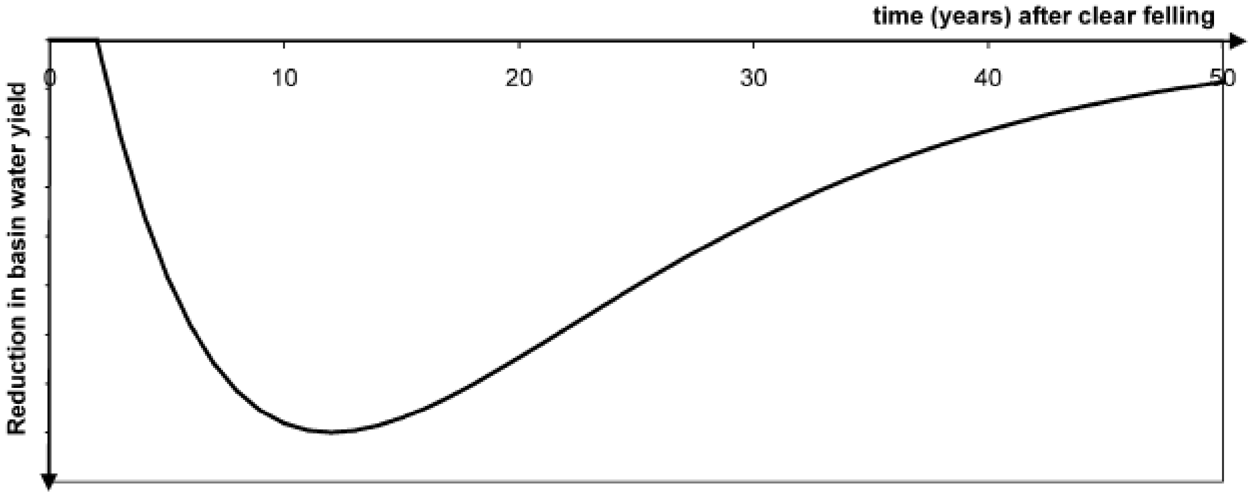
> *All plants evaporate water through their leaves. This water is extracted from the soil root zone, and the rate of evaporation depends on the weather, the available soil moisture, and the total area of leaves in the vegetation (trees and understorey). There are differences between various forest types, but basically different forests have evolved to make optimum use of the available rainfall to ensure their survival. Streamflow in drier periods is the "left-over rainfall" that passes beyond the root zone and exudes into the stream from boggy areas and the water table next to the stream. In storms, water runoff also occurs where the rainfall is intense enough to exceed the capacity of the soil to absorb it, or where the soil is already saturated. This runoff results in rapid increases in streamflow, or floods during major storms.*
>
> *For example, during an average year at a south eastern Australian catchment where the annual rainfall is 1000 mm, the forest canopy may intercept and evaporate 150 mm of the rainfall before it reaches the ground. The forest may consume a further 750 mm by plant transpiration, leaving only 100 mm to appear as streamflow (this is equivalent to a water*

yield of 1 megalitre per hectare). Of this 100 mm, 80 mm may occur as short-term runoff during storms, while the remaining 20 mm occurs as sustained dry-weather flow or "baseflow".

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, reduction and recovery of water yields following loss of overstorey.

Tree water use has been found to be primarily related to sapwood extent, with the thickness of sapwood, and the basal area of sapwood declining as forests age, even though overall basal area increases (Dunn and Connor 1994, Roberts *et al.* 2001, Macfarlane and Silberstein 2009, Buckley *et.al.* 2012, Benyon *et. al.* 2017).

Dunn and Connor (1994) made diurnal measurements of sap velocity in 50-, 90-, 150- and 230-year-old mountain ash (*Eucalyptus regnans* F. Muell.) forests in the North Maroondah catchment finding "*The measurements have shown a significant decrease in overstorey water use with age. At the extreme, measured daily water use of the mature forest is 56% smaller than that of the regrowth forest.",* concluding:

> *There was a significant decline with age in the overstory sapwood conducting area of these forests. In order of increasing age, the values were 6.7, 6.1, 4.2 and 4.0 m^{-2} ha^{-1}, respectively. ... Annual water use decreased with forest age from 679 mm for the 50-year-old stand to 296 mm for the 230-year-old stand. ... The annual water use of the intermediate-aged stands was 610 and 365 mm for the 90- and 150-year-old stands, respectively.*

Roberts *et al.* (2001) studied water use of different aged stands of *Eucalyptus sieberi* (Silvertop Ash) within Yambulla State Forest, with an average annual rainfall of 900 mm per year, finding:

> *Stand sapwood area declined with age from 11 m^2 ha^{-1} in the 14 year old forest, to 6.5 m^2 ha^{-1} in the 45 year old forest, to 3.1 m^2 ha^{-1} in the 160 year old forest. LAI was 3.6, 4.0, and 3.4 for the 14, 45, and 160 year old plots, respectively. Because of the difference in sapwood area, plot transpiration declined with age from 2.2 mm per day in 14 year old forest, 1.4 mm per day in 45 year old forest, to 0.8 mm per day in 160 year old forest.*

Macfarlane and Silberstein (2009) assessed the water use related characteristics of regrowth and old-growth forest in the high (1200 mm $year^{-1}$) rainfall zone of jarrah forest in Western Australia, finding (SAI sapwood area index):

> *The old-growth stands had more basal area but less canopy cover, less leaf area and thinner sapwood. ...SAI of the regrowth forest at Dwellingup (7.0 m^2 ha^{-1}) was nearly double that of the old growth 3.7 m^2 ha^{-1}),..*
>
> *... At the old-growth site, daily transpiration rose from 0.4 mm day^{-1} in winter to 0.8 mm day^{-1} in spring-summer. In contrast, at the regrowth site transpiration increased from 0.8 mm day^{-1} in winter to 1.7 mm day^{-1} in spring-summer. Annual water use by the overstorey trees was estimated to be ~200 mm $year^{-1}$ for the oldgrowth stand and ~420 mm $year^{-1}$ at the regrowth stand, which is 17% and 35% of annual rainfall, respectively.*

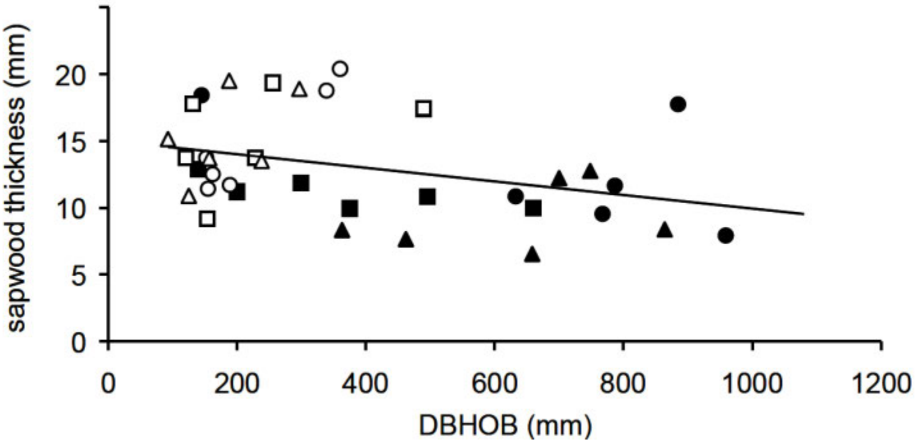


Figure 5 from Macfarlane and Silberstein (2009) sapwood thickness versus tree diameter (measured at breast height over bark, DBHOB) at the old-growth (closed symbols) and regrowth (open symbols) study sites.

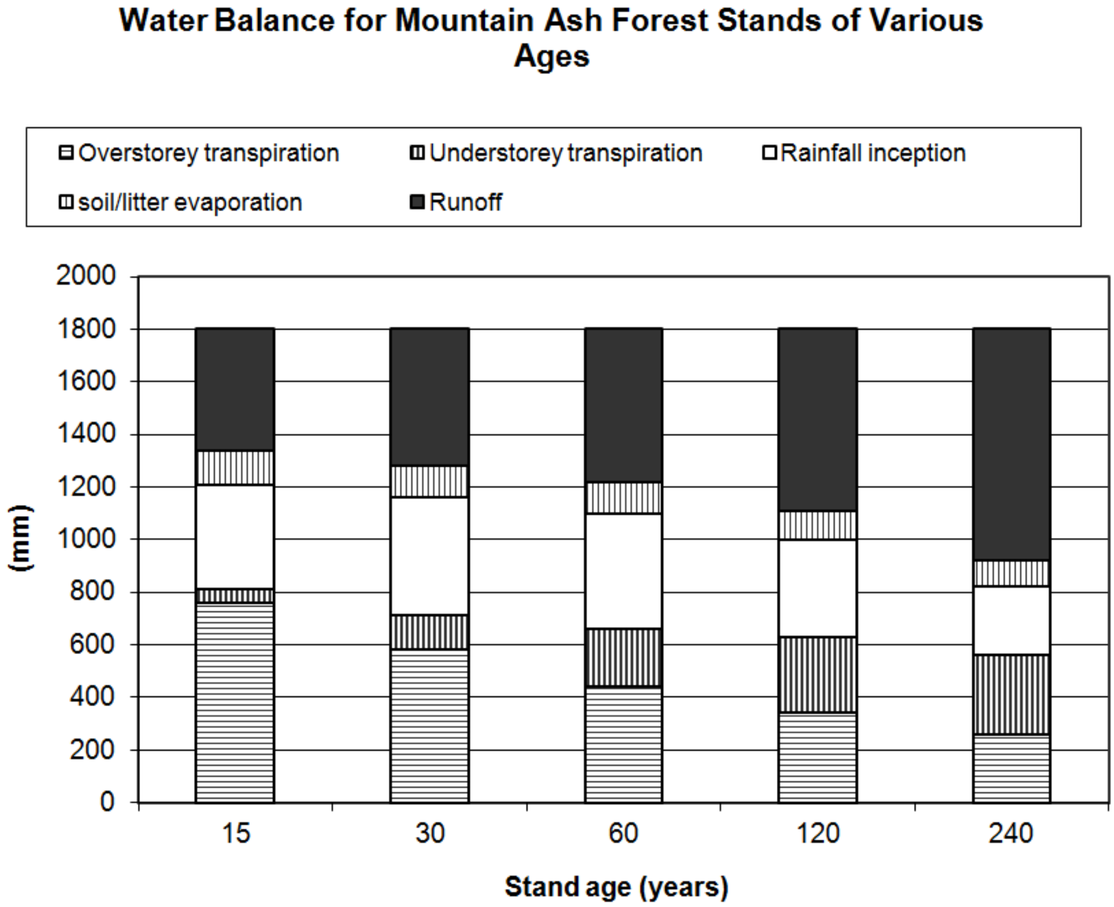
For 'actual evapotranspiration' (E_a) Benyon *et. al.* (2017) identify:

> *... in even-aged eucalypt forests in south-eastern Australia, catchment mean overstorey sapwood area index (SAI), estimated from a relationship between stand mean sapwood thickness and tree density (trees ha^{-1}), applied to repeated measurements of tree density and mean tree diameter over several decades, was strongly correlated with catchment mean annual E_a, estimated as annual precipitation minus annual streamflow (Benyon et al., 2015).*

From their study of Mountain Ash forests, Benyon *et. al.* (2017) concluded (E_a actual evapotranspiration, SAI sapwood area index):

> *In non-water-limited eucalypt forests, overstorey sapwood area index is strongly correlated with annual overstorey transpiration and total evapotranspiration. Interception loss from the overstorey is also positively correlated with overstorey SAI. ... Variation in SAI explained almost 90% of the between-plot variation in annual E_a across three separate studies in non-water-limited eucalypt forests. Our results support the use of measured spatial and temporal variations in SAI for mapping mean annual E_a (Jaskierniak et al., 2015b) and for modelling longterm streamflows in ungauged catchments (Jaskierniak et al.,2016).*

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 (from Vertessy et. al. 1998)

The generalised pattern following heavy and extensive logging of an oldgrowth forest is for there to be an initial increase in runoff from disturbed areas 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.*

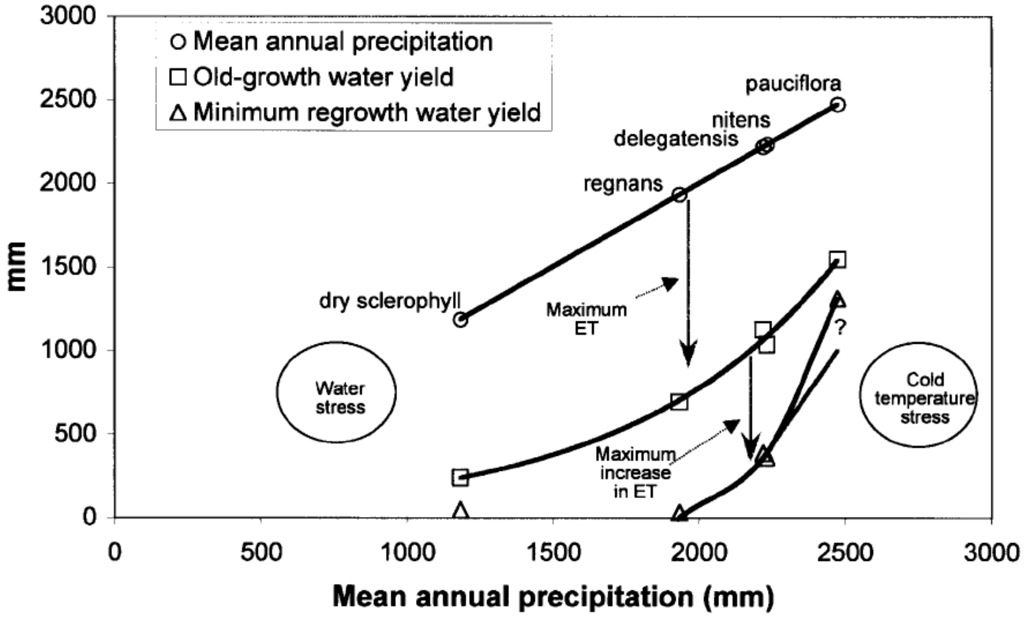
Cornish and Vertessy (2001) elaborate:

> *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.*

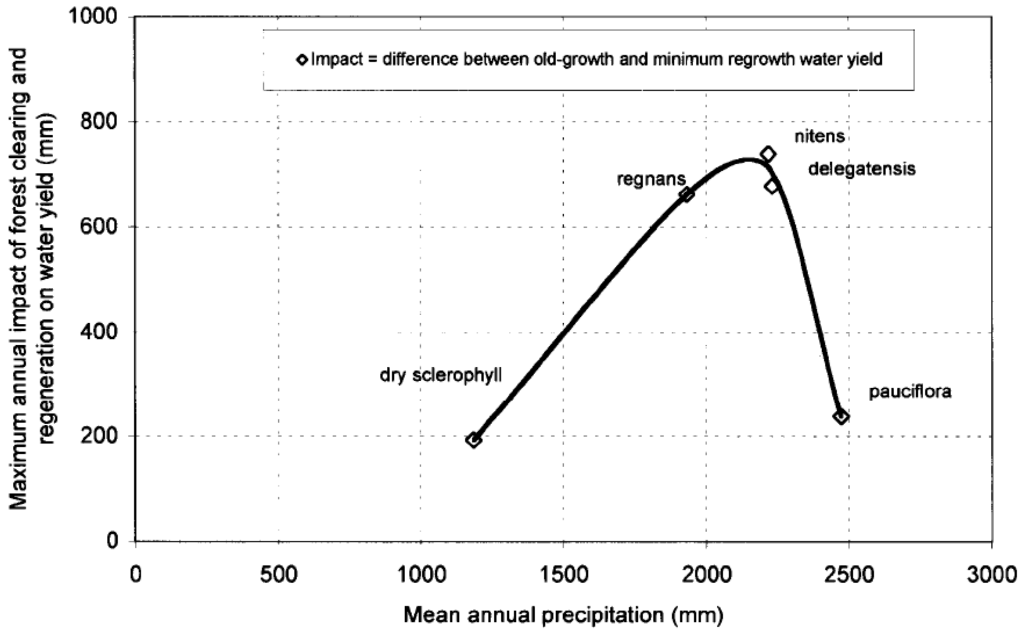
Vertessy (1999) notes that "the maximum decrease in annual streamflow is over 60 mm per 10% of forest area treated, which is similar to the maximum reductions noted for Victorian mountain ash forests".

The process of increasing water use by regrowth is relatively well understood and has been found to apply across forests, though localised impacts are 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.

For example 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)



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

Given the abundant evidence of how forest maturity affects water yields and the significance of the impacts it is grossly irresponsible for any water strategy not to take this into consideration. You have not done due diligence.

2. Protect and enhance the environment Improve the health and integrity of environmental systems and assets, including by improving water quality.

The headwaters of our rivers are vital to their health as this is where most of the interaction between the land and waters occurs. The retention of undisturbed buffers around streams is essential to trap sediments from entering waters, stabilise stream banks, shade waters, provide food and other resources to the aquatic environment, and maintain riparian habitat. The scientific evidence (Hansen *et. al.* 2010) is that stream buffers should be at least 30m wide and implemented around the saturated zone to maintain water quality and stream health. The protection and restoration of riparian buffers has to be the key focus of any strategy to improve water quality and aquatic habitats.

Headwater streams are of overwhelming importance for catchment health as this is where most of the interaction between the terrestrial and aquatic realms occurs. The science is that we should be establishing buffers at least 30m wide around these headwater streams.

The riparian zone is the interface between a stream (and other waterbodies) and land through groundwater, subsurface flows and flooding. The riparian zone can be considered to encompass the entire extent of a stream's floodplain. Riparian vegetation has a direct influence on streams and is influenced by streams.

Hansen *et. al.* (2010) note:

> *The riparian zone (riparia) is the interface between aquatic and terrestrial environments (Naiman and Décamps, 1997) and it mediates the flow of energy, and physical and biotic vectors between the two (Lake, 2005, Naiman et al., 2005). Consequently, riparia are often environments of exceptionally high diversity. The importance of intact riparian zones is universally acknowledged as critical to aquatic-terrestrial ecosystem function and ultimately, to waterway health.*

Riparian vegetation is enhanced by increased soil moisture, increased humidity and nutrients from flood events. They provide resources for a broad range of fauna, especially during droughts. Numerous species are primarily associated with riparian habitats for at least part of their life-cycles, this includes a multitude of plants and invertebrates, most frogs and tortoises, some lizards and birds, and a few mammals (i.e. Platypus, Water Rat and Fishing Bat). Riparian vegetation also regulates the health and functioning of aquatic ecosystems, is the basis of aquatic food chains in upper catchments, and provide the branches and logs that structure many instream habitats for numerous aquatic invertebrates and many fish.

The health of streams is directly related to the health and functioning of riparian vegetation. Riparian buffers serve several functions:

- shading of streams and minimising fluctuations in water temperatures
- reducing the volumes of overland flows entering streams
- trapping sediments and associated pollutants moving from upslope towards streams
- maintenance of stable stream banks and channels;
- providing wood, leaf litter, fruits, flowers, insects and other resource inputs to streams;
- maintenance of habitat requirements for many aquatic and terrestrial species; and,
- provide corridors for the movement of a suite of terrestrial species.

Price and Tubman (2007) identify that riparian vegetation provides many ecosystem services, including:

- *trap sediment, nutrients and other contaminants before they reach the waterway and reduce water quality for downstream users,*
- *lower water tables,*
- *reduce rates of bank erosion and loss of valuable land,*
- *control nuisance aquatic plants through shading,*
- *help ensure healthy stream ecosystems,*
- *provide a source of food and habitat for stream animals,*
- *provide an important location for conservation and movement of wildlife,*
- *help to maintain agricultural productivity and support mixed enterprises,*
- *provide recreation and maintain aesthetically pleasing landscapes, and*
- *provide cultural and spiritual enrichment for people.*

The key threatening process declaration under the *Fisheries Management Act 1994* for 'degradation of native riparian vegetation along New South Wales water courses' states:

> *1. Riparian vegetation refers to the vegetation fringing water courses and can be defined as any vegetation on land which adjoins, directly influences, or is influenced by a body of water. Riparian habitats thus include land immediately alongside large and small creeks and rivers, including the river bank itself; gullies and dips that sometimes run with surface water; areas around lakes; wetlands on river floodplains that interact with the river in times of flood.*
>
> ...
>
> *4. Degradation of riparian vegetation has a major influence on stream ecosystems by;*
>
> - *Increasing the amount of sediment and nutrients reaching streams as runoff, and increasing light penetration of the water body. These inputs have the combined effect of smothering benthic communities and increasing harmful algal growth.*
> - *Reducing the inputs of organic carbon, via leaves, twigs, and branches. Terrestrially derived carbon inputs are the major energy source in most stream ecosystems.*
> - *Reducing the amount of large woody debris entering the aquatic ecosystem and thereby negatively impacting on habitat and spawning sites of several vulnerable and endangered species listed under the Fisheries Management Act, 1994.*
> - *Destabilising river banks.*
> - *Reducing the amount of overhanging riparian vegetation resulting in a loss of shade and shelter for fish.*

Riparian land is „any land which adjoins, directly influences, or is influenced by a body of water", where the body of water could be a stream (permanent or intermittent), river, lake, or wetland.

Price and Tubman (2007) recognise:

> *Riparian land is important because it is often the most fertile and productive part of the landscape, in terms of both agricultural production and natural ecosystems. It often has deeper and better quality soils than the surrounding hill slopes due to past erosion and river deposition and, because of its position lower in the landscape, often retains moisture over a longer period.*

Riparian vegetation only represents a small portion of the landscape, yet is of the utmost importance in maintaining terrestrial and aquatic biodiversity. Many species of plants and animals only occur, or are in far greater abundance, in riparian areas, with their importance increasing during dry periods (Belsky *et. al.* 1999, Burrows 2000, Jansen and Robertson 2001, Allan 2004, Price and Tubman 2007, Martin and McIntyre 2007, Martin 2010). As noted by Burrows (2000):

> *Although they occupy only a relatively small percentage of land area, riparian zones play a disproportionately important role in the overall environment. Per unit area, riparian zones*

have considerably higher plant and animal biomass and diversity, are more structurally and floristically diverse, provide critical refuge habitats during dry periods and buffer waterways and downstream environments from the effects of surrounding environmental conditions and land uses.

Price and Tubman (2007) also recognise that:

... vegetation on riparian land regulates in-stream primary production through shading (reduced light and water temperature); supplies energy and nutrients (in the form of litter, fruits, terrestrial arthropods and other organic matter) essential to aquatic organisms; and provides essential aquatic habitat by way of large pieces of wood that fall into the stream and through root-protection of undercut banks.

Kauffman and Krueger (1984) observe:

Riparian vegetation produces the bulk of the detritus that provides up to 90% of the organic matter necessary to support headwater stream communities (Cummins and Spengler 1978). In these tributaries of forest ecosystems 99% of the stream energy input may be imported from bordering riparian vegetation (i.e., it is heterotrophic) and only 1% derived from stream photosynthesis by attached algae (periphyten) and mosses (Cummins 1974). Berner (in Kennedy 1977) found that even in large streams such as the Missouri River, 54% of the organic matter ingested by fish is of terrestrial origin.

Belsky *et. al.* (1999) consider:

Rooted streamside plants retard streambank erosion, filter sediments out of the water, build up and stabilize streambanks and streambeds, and provide shade, food, and nutrients for aquatic and riparian species ... Healthy riparian areas also act as giant sponges during flood events, raising water tables and maintaining a source of streamwater during dry seasons. The result is a more stable streamflow throughout the year...

Burrows (2000) cites a study within the Burdekin catchment that found the riparian zones to contain twice as many bird species than adjacent woodlands, noting:

Nearly one-third of the bird species were either found in greater abundance in the riparian systems or were only found in riparian systems. Several mammal and reptile species and most amphibian species were also dependent on the riparian zone, not being found in adjacent woodlands.

As noted by Allan (2004) there have already been profound changes to hydrology of many catchments:

Geomorphological changes brought about by multiple human activities likely have produced lasting, complex, and often unappreciated changes in physical structure and hydrology of river systems. Landscape changes that occurred within a few decades of European settlement of New South Wales, Australia, including clearance of riparian and floodplain vegetation and draining of swamps, have fundamentally altered river structure throughout virtually the entire Bega catchment (Brierley et al. 1999). Extensive habitat transformation has resulted, including channel widening and infilling of pools in lowland sections and incision of head-water channels owing to more efficient downstream water conveyance and down-stream export of sediments. Overall structural complexity has been reduced and lateral connectivity is largely lost in middle reaches but is now increased in the lowlands.

Hansen *et. al.* (2010) consider"

Disturbance and modifications to catchments through clearing vegetation for agriculture and grazing of livestock have resulted in extensive degradation of riparian zones and their adjacent waterbodies. This is predominantly through increased transfer of nutrients, sediment and pollutants into streams, exacerbated bed and bank erosion, and loss of in-

stream and terrestrial biodiversity via degradation of riparian and aquatic vegetation and loss of important habitat structure such as large wood.

From their review of the importance of the riparian zone to freshwater fish, Pusey and Arthington (2003) note:

> *Given the number and importance of links between riparian and lotic ecosystems, it is not surprising that spatial and temporal variation in fish assemblage composition and characteristics (i.e. species richness, abundance, biomass) have been linked to variation in riparian cover ... or that fish communities are adversely affected by riparian destruction and recover only when riparian integrity is re-established ...*

Pusey and Arthington (2003) identify a large variety of known and potential impacts on fish as a consequence of changes to riparian vegetation, summarising in part that:

> *Impacts associated with changes in light quality range from increased egg and larval mortality due to increased ultraviolet (UV) B irradiation and a decreased ability to discriminate between potential mates to increased conspicuousness to predators. ... The interception of terrestrial sediments and nutrients by the riparian zone has important consequences for stream fish, maintaining habitat structure, water clarity and food-web structure. Coarse organic matter donated to the aquatic environment by the riparian zones has a large range of influences on stream habitat, which, in turn, affect biodiversity and a range of process, such as fish reproduction and predation. Terrestrial matter is also consumed directly by fish and may be a very important source of energy in some Australian systems and under certain circumstances.*

Martin (2010) identifies that:

> ...*local riparian habitat characteristics significantly affected the relative abundance of over 80% of bird species' ... local riparian habitat condition as a result of grazing and tree clearing was the primary determinant of bird species composition and abundance. Restoring trees along cleared riparian habitat will result in a dramatic increase in bird species richness, relative abundance and composition*.

Allan (2004) summarises some of the consequences of the degradation and loss of riparian vegetation:

> *Wherever agriculture or other anthropogenic activity extends to the stream margin and natural riparian forest is removed, streams are usually warmer during summer and receive fewer energy inputs as leaf litter, and primary production usually increases (Quinn 2000). Bank stability may decrease, ... and the amount of large wood in the stream declines markedly (Johnson et al. 2003). Stable wood substrate in streams performs multiple functions, influencing channel features and local flow and habitat and providing cover for fish, perching habitat for invertebrates, and a substrate for biofilm and algal colonization (Gregory et al. 2003). Its absence can have a profound influence ...*

2.1 Widths of Buffers

Hansen *et. al.* (2010) recognise *"Maximising lateral and longitudinal extent of intact riparian zones, starting in the headwaters, provides the best protection for the waterway".* There is no maximum width for riparian buffers, though there are minimum widths below which the likelihood of significant impacts should be considered unacceptable.

Regrettably, while there have been a variety of studies that help inform the design of riparian buffers, there has been insufficient studies to assess the effectiveness of various buffer widths in protecting various values in Australia. From their review of the scientific literature Hansen *et. al.* (2010) concluded that research *"is inadequate and thus hinders development of meaningful* *management guidelines for maintaining or restoring aquatic-terrestrial ecosystems"*, lamenting *"the opportunities to gain new information from existing management programs are frequently overlooked"*. Given that NSW Government agencies espouse "adaptive management", the failure to rigorously assess the effectiveness of buffer strips in over 40 years since the Standard Erosion Guidelines were first adopted is reprehensible.

Unfortunately, because logging has been constrained in riparian zones in the past they are now sought after for logging by the timber industry. Management of riparian zones is therefore a political issue. Ecological requirements are usually severely compromised by the quest for resources.

It is along the smallest streams and drainage lines where most of the interaction between terrestrial and aquatic environments occurs. Small headwater streams generally drain catchments smaller than two square kilometres and can constitute over 75% of the stream length in a drainage basin (Barmuta *et. al.* 2009).

Lowe and Likens (2005) consider:

> *Everywhere on Earth, streams and rivers occur in hierarchical networks resembling the branching pattern of a tree, with smaller branches joining to form larger branches as water travels from uplands to lakes, estuaries, and seas. The finest branches of these networks, beginning where water flowing overland first coalesces to form a discernible channel, are called headwater streams. ... because of their small size, these streams are often missing from maps that guide the management of natural resources.*
>
> *...*
>
> *There is growing evidence that the water quality, biodiversity, and ecological health of freshwater systems depend on functions provided by headwater streams, which are similar in their importance to the fine branches of the human respiratory system in the lung.*
>
> *...*
>
> *Headwaters are a source of life. They are critical habitat for rare and endangered freshwater species, and guardians of many downstream resources and ecosystem services on which humans rely ...*

Small headwater streams are where most of the inputs of energy, sediments, nutrients and pollutants from the adjacent terrestrial environment occurs. These streams are often ephemeral or intermittently flow, yet they can harbour endemic invertebrates - many with highly restricted distributions (Barmuta *et. al.* 2009).

Barmuta *et. al.* (2009) consider:

> *For forested headwaters in upland areas, the streams tend to be steep, with a stair-step longitudinal profile, and the catchments are subject to unpredictable land-slips or debris flows. Hydrologically, the permanent streams tend to derive a greater proportion of their modal flows from groundwater than downstream segments, and they tend to be shallow with slow water velocities (Gomi et al. 2002). Because of their small size and large contact with the adjacent terrestrial habitat, flows are responsive to runoff events ...*
>
> *...*
>
> *In forested areas, the riparian vegetation usually forms a closed canopy, and most of the energy for the in-stream food web is provided by allochthonously-derived inputs of leaf litter (often termed CPOM: coarse particulate organic matter), and leaching of this material yields large quantities of dissolved organic matter (DOM) which can be augmented by direct inputs from interflow, groundwater or overland flow. The DOM pool can be up to 10 times greater than the pool of particulate organic matter and it provides energy and nutrients to in-stream biofilms that form the basal food resource for many invertebrate consumers ...*

Hansen *et. al.* (2010) state:

> *The best opportunity for mitigation of catchment-scale disturbances is by the protection or rehabilitation of headwater systems due to their demonstrated capacity for greatest regulation of water quality and highest contribution to regional biodiversity"*.
>
> ...
>
> *Erosion in headwater areas makes a disproportionately high contribution to waterway sedimentation and elevated nutrient levels (Lowe and Likens, 2005, Naiman et al., 2005). Ephemeral streams also contribute large amounts sediment and nutrients that are mobilised during storm events (Wenger, 1999, Fisher et al., 2004)*

Davies and Nelson (1993) note that *"the role of first-order streams in sediment transport from hillslopes experiencing accelerated erosion has long been recognised".* concluding that *"enhanced fine sediment movement in streams as a result of logging is most likely to occur owing to disturbance of headwater stream channels"*.

Croke and Hairsine (1995) note *"in general it is agreed that buffer strips should extend to the springhead or runoff confluence point of any sub-catchment and should be well upstream of any existing channel or streambed, since flow will occur at a higher point in the catchment once the forest has been cleared."*

Despite the headwaters of catchments warranting the greatest protection, in current practice buffer strips along streams increase in size with stream size. Bren (1999) notes that the problem with this is that *"compared to more rigorous methods this under-protects the stream head, but overprotects divergent areas downstream. A method based on a constant ratio of upslope contributing area to buffer area gave the widest buffers at the stream head and buffers of diminishing width as one moved downstream."*. Bren notes that having relatively wider buffers for the smaller headwater streams *"makes sense hydrologically but is probably politically unacceptable."*

Munks (1996) reviewed the available literature to recommend buffer widths for various functions.

Munks (1996) Recommended buffer widths for various functions of riparian vegetation

Function of the Riparian Vegetation	**Recommended Buffer Width (from edge of bank)**
Water Quality, Sediment, Pollutants etc.	20-50m (streams) 40-100m (rivers)
Bank Stabilisation	10 m + (rivers and streams)
Provision of habitat for terrestrial animals	50-60 m (rivers)
Provision of food, habitat and protection of stream fauna	30-100 m (streams)

Based on her review Munks (1996) recommend minimum buffer widths for streams.

Table 3.5. Munks (1996) recommended minimum buffer widths for streams:

Type of River or Stream	**Minimum width from stream bank***
Main Rivers	40 m
Creeks and streams from the point where their catchment exceeds 100 ha	30 m
Small streams with a catchment of 50 to 100 ha	30-50 m
Small streams, tributaries, gully and drainage lines which only carry surface water during periods of heavy rainfall	30 m

* If the slope of adjacent land running down to the stream is greater than 10%, the recommended width is increased to 50m.

Munks (1996) also considers that "adequate widths of riparian vegetation for fauna protection needs to be species-specific."

Hansen et. al. (2010) undertook a meta-analysis of >200 riparian studies and recommended riparian buffer widths of between 30 and 200 m dependant on land use intensity and the management objective. Hansen et. al. (2010) considered forestry operations and grazing at low stocking rates (<5 Dry Sheep Equivalents/ha/annum all stock) as being relatively low impact. Though the impacts of logging operations vary with the logging intensity, slopes and soils.

Hansen *et. al.* (2010) Minimum width recommendations for Victorian riparian zones based upon available scientific literature and adjusted using expert opinion, where appropriate, to account for known differences between Victorian and international systems. All widths are in metres.

Landscape context /Management Objective	Land Use Intensity High	Land Use Intensity Moderate	Land Use Intensity Low	Wetland/lowland floodplain/off-stream water bodies	Steep catchments/cleared hillslopes/low order streams
Improve water quality	60	45	30	120	40
Moderate stream temperatures	95	65	35	40	35
Provide food and resources	95	65	35	40	35
Improve in-stream biodiversity	100	70	40	Variable*	40
Improve terrestrial biodiversity	200	150	100	Variable*	200

* Variability in width is related to the lateral extent of hydrological connectivity and thus, any recommendation will be site specific.

In forestry planning stream buffers are usually applied to act as sediment and nutrient filters for subsurface and overland flows (i.e. Barling and Moore 1994). They are more effective for removing sediment than nutrients from the flow and are more effective at removing coarse rather than fine sediments (i.e. Barling and Moore 1994). They are also most effective when the flow is shallow, slow, and enters the strip uniformly along its length (i.e. Barling and Moore 1994). Barling and Moore (1994) note that *"in hilly terrain flow rapidly concentrates, producing higher flow velocities and larger flow depths that can rapidly submerge the vegetation and significantly reduce the effectiveness of the filter strip"*.

Croke and Hairsine (1995) categorised streamside buffers as Streamside Reserves (no logging or machinery disturbance) and Filter Strips (logging, but no machinery disturbance), and made recommendations for their minimum widths along streams and around wetlands based primarily on controlling overland flows of sediments. All their buffers are classed as Streamside Reserves except for those on drainage lines.

Table 3.6. Croke and Hairsine's (1995) recommended "Minimum Streamside Reserve and Filter Strip Widths according to stream type"

Type of River or Stream	Minimum widths
Rivers, Lakes and Streams used for water supply	100 m
Creeks and streams from the point where their catchment exceeds 100 ha	40 m
Small streams with a catchment less than 100 ha	30 m
Temporary streams flowing more than 1 in 5 years and carries water for some time (weeks) after rainfall.	20 m

Drainage lines carrying water only during or immediately (hours, days) after rainfall	10 m
Permanent springs, swampy ground, wetlands and bodies of standing water	30 m

As a compromise back in 2001 the Department of Lands and Water Conservation (Boyd 2001) specifically advised for the Richmond Catchment that "*Protected land should be a width of **20m from the high bank** of all watercourses*".

Croke and Hairsine (1995) note that Streamside Reserves must be:

> *"extended beyond the minimum widths wherever necessary according to a field assessment of the size and flow of the stream or spring, the size and nature of the soak, swampy ground or body of standing water; the nature of the surrounding topography and soil type, the intensity and magnitude of the harvesting operation; the riparian habitat value; and the proximity and physical design of any water supply take-off and distribution system."*

Croke and Hairsine consider that extensions of Streamside Reserve widths must "be determined according to soil type, hazard class slope, and other climatic and geomorphic variables relevant to the region".

Croke and Hairsine (1995) also emphasise that "It is crucial when defining buffer strips in the field that all sources of runoff generation are included within the buffer strip zone. It is essential to incorporate the 'saturated zone', which is the area along the stream or drainage line that is permanently saturated (e.g. swampy ground) or becomes saturated (e.g, seepage area) with the onset of rain". They consider that "this is recognisable through the existence of saturated soil or presence of a vegetation associated with frequently saturated soil".

In 2000 the wetland systems in the Richmond catchment were mapped by API by Owen Early, this included drainage depressions, flood channels and floodplains. If we wanted to achieve the best environmental outcome then such riparian areas would be protected in their entirety, and the required buffers applied to them, rather than just to the main channels.

2.2 Restoring and improving buffers in logging:

The 0-5m buffers applied to headwater streams in public and private logging operations in north-east NSW are patently grossly inadequate to mitigate logging impacts on streams and have no scientific basis. They are therefore a major threat to riparian vegetation and the health of our waterways and their inhabitants, and must urgently be expanded to provide adequate protection.

The Environment Protection Licence (EPL) was applied to forestry operations on public lands in 1999 as an outcome of the Regional Forest Agreement. It required buffers of 10-15m on unmapped streams and 10-20m on first order streams, depending on erodibility - mostly 10m.

The fisheries licence also required these buffers on both mapped and unmapped streams within 100km upstream of threatened fish.

The threatened Species Licence only required buffers on mapped streams.

In May 2004 the Forestry Corporation was successful in getting the Environment Protection Licence amended to have the effect of excluding most of its operations from requiring licences under the EPL.

Over 90% of their logging operations were no longer subject to the EPLs.

This was done specifically to allow logging of unmapped drainage lines, and the Forestry Corporation wasted no time in getting into them.

In 2009 NEFA caught the Forestry Corporation logging some 20 ha of unmapped drainage lines in Yabbra State Forest upstream from an important population of the Endangered Eastern Freshwater Cod. Fisheries NSW upheld our complaint and issued a Penalty Infringement Notice and $500 fine for failing to mark exclusion boundaries on unmapped drainage lines, and a Penalty Infringement Notice and $500 fine for logging, bulldozing and burning within 10m of these unmapped streams

They had apparently been ignoring the requirements of the Fisheries Licence for the proceeding 5 years in their logging spree.

NEFA then focussed of trying to force Fisheries NSW to identify threatened fish habitat so that the required protection of threatened fish would be implemented. By early 2017 we had succeeded in getting buffers reapplied to most unmapped drainage lines on State Forests in north-east NSW.

For the Coastal Integrated Forestry Operations Approval (CIFOA) the Threatened Species Expert Panel (EPA 2018) opposed the opening up of protected riparian areas protected for the past 20 years for logging. For example Brad Law, DPI Forestry, stated:

> *"In some areas where areas once mapped as riparian buffers are no longer identified then there would be a loss of habitat protected for the past 20 year period. Given the intensity of operations over the last 10 years, it would be important to try to ensure these areas remain protected"*

The EPA representative Brian Tolhurst stated:

> *"No further loss or impact on the retained riparian areas that have been protected to date under the existing rule set should occur. The expert panel agreed that these areas were the few areas seen on the site visit that still retained habitat elements and the diversity, form and structure of a native forest.*
>
> *...*
>
> *I am not convinced that the proposed riparian buffers are adequate for ecological protection of these features. ...".*

There was no expert review of the new erosion and stream buffer requirements for impacts on streams.

The new Coastal IFOA reduces buffers on all headwater streams in catchments less than 20ha from 10-20m down to 5m. They now only need to implement 10m buffers within 2km upstream of a threatened fish rather than 100km. Streams in catchments less than 20ha represent 76% of streams on State Forests in the Richmond River catchment. Stream buffers will be retained at around 20m in catchments 20-100ha, 30m in catchments 100-400ha and 50m in catchments 400+ha.

The Threatened Species Licence requirement to increase riparian protection in the vicinity of various threatened animals have been removed.

The new CIFOA removes the need to protect 30m riparian buffers on 1st and 2nd order streams within 200m of records of the Golden-tipped Bat, Fleay's Frog, Giant Barred Frog, and Stuttering Frog. Similar protection for the Fishing Bat was removed in 2013. Areas protected for the last 20 years will now be able to be logged.

In a 2016 assessment NEFA did of representative logging plans across the Richmond and Clarence catchments we found that species specific exclusions accounted for 14% of the riparian areas excluded from logging.

In addition to this, the requirement to reduce erosion in a 10m protection zone around stream buffers by not roading along them has been removed after we caught them doing extensive roading in them in Sugarloaf State Forest in 2016.

Without accounting for the species reductions the new reduction of stream buffers from 10m to 5m will result in the loss of some 22,000 km/hectares of currently protected stream buffers north from the Hunter River. For the Richmond catchment this will equate to some 2,500 km/ha of existing stream buffers on State Forests.

In addition to this the new rules allow for significantly increased logging intensity across all forests, equating to around a doubling of the amount of trees that can be removed in any operation. This will dramatically increase erosion. We should be increasing buffers not reducing them.

The Private Native Forestry (PNF) Code is in the process of being re-written, currently it gives the following buffers:

Table F: Riparian exclusion and riparian buffer zones

Drainage feature	Riparian exclusion zone distance from drainage feature	Riparian buffer zone distance beyond riparian exclusion zone
Mapped first-order streams	5 metres	10 metres
Mapped second-order streams	5 metres	20 metres
Mapped third-order or higher streams	5 metres	30 metres
Prescribed Streams	20 metres	15 metres

PNF logging operations are excluded from riparian exclusion zones, though modified logging is allowed in riparian buffer zones. Machinery exclusion zones must be applied to all unmapped drainage lines, though they can be fully logged. Forest operations must not occur in any wetland or within 20 metres of any wetland.

The riparian buffer widths of 0-5m applied by the PNF Code for unmapped, 1st, 2nd and 3rd order streams are significantly less than the 10-20m required by the EPL for public lands, the 30-50m identified by Munks (1996) for small streams, tributaries, gully and drainage lines in catchments less than 100 ha, or the 35-40m (up to 200m to improve terrestrial biodiversity) identified by Hansen *et. al.* (2010) for steep catchments and low order streams, or even the 20-30m for erosion control identified by Croke and Hairsine (1995) for temporary and small streams in catchments less than 100ha. Similarly the 20m buffers for wetlands are significantly less than the 10-40m buffers identified for public lands.

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