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Comment on *New Insights into Forest Hydrology with Forest Flows Programme – Radiata Pine Catchments' Water Use and Release* by D.F. Meason et al. (2025)

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Figure 1: Interception loss from dense pine canopies can be substantial, particularly under prolonged, low-intensity rainfall

Abstract

This comment challenges claims made by the Forest Flows Programme (Meason et al., 2025) regarding the water use of *Pinus radiata* plantations and the water yield from pine-forested catchments across New Zealand. Using robust, previously established evidence, it is argued here that instead of 'dispelling some commonly-held beliefs', Meason et al. have created new forest hydrological myths by underestimating pine-tree water use and overestimating subsurface flows based on an erroneous conceptualisation of key processes and water-balance components. In the authors' view, this not only renders their conclusions in error and in need of further scrutiny, but also risks an inaccurate scientific understanding of the hydrological role of plantation forests, which could lead to misleading forest- and water-related policy decision-making.

Introduction

Reliable estimates of forest hydrological components, vegetation water use in particular, are essential for understanding forest influences on catchment hydrology and managing water resources. Evapotranspiration (ET) – encompassing rainfall interception (evaporation of water from wet canopies), transpiration (evaporation from dry foliage) and evaporation from litter/soil – represents the largest component in the global terrestrial water balance (Fisher et al., 2017).

Even modest errors in its estimation can lead to substantial uncertainty in the inferred magnitude of groundwater recharge, streamflow and catchment water yield. In forested catchments, ET plays a critical role in determining how rainfall is partitioned among soil and groundwater storages, deep percolation and streamflow. Reliable estimates of ET are therefore not only central to water resources management, but also to forest management, afforestation planning and hydrological modelling (increasingly important under climate change).

For decades, robust field measurements, paired-catchment experiments and modelling studies in New Zealand and internationally have provided consistent evidence on the magnitude of forest water use (i.e. ET) and water yield relative to other land-cover types (shrubland, grassland, agricultural crops). Forest water use is generally markedly higher than that for shorter vegetation types, owing to greater leaf area and higher interception losses, as well as deeper root systems exploiting larger volumes of soil (Sun et al., 2025).

Against a backdrop of concerns about the potentially adverse hydrological effects of converting large tracts of non-forest land to fast-growing exotic plantation forests (cf. Cao et al., 2009), the recent paper by Meason et al. (2025) in the *New Zealand Journal of Forestry* reports *Pinus radiata* water-use values for five sites across New Zealand (at an average 25% of annual rainfall). However, these values are substantially lower than those established from previous research, both nationally and internationally. Here, we address three major issues of concern in the Meason et al. paper and provide alternative established evidence:

- First, the study contains a number of conceptual inaccuracies in its treatment of key hydrological processes and fluxes
- Second, there is no clear description regarding the methods used to measure ET and subsurface flows
- Third, acceptance of the underestimated values derived for ET (and streamflow) risks an inaccurate representation of the role of plantation forests in New Zealand catchment water balances, which would misinform both scientific understanding and water policy decision-making.

Instead, we argue that most of the 'new insights' provided by Meason et al. are based on substantially underestimated tree water-use values and erroneous conceptualisation, rendering their conclusions unreliable and likely in need of major revision.

Conceptual inaccuracies

Figure 1 in Meason et al. contains a number of conceptual inaccuracies relating to key components of the forest hydrological water budget that require correction. 'Streamflow' (component 5) is defined as 'Rainfall that falls directly into streams and rivers or from groundwater'. 'Runoff' (component 7) is termed 'Rainfall that can't infiltrate forest litter and soil [and] runs over the forest floor and into streams' (yet was not included in their earlier definition of streamflow). Further, Equation (1) in Meason et al. incorrectly equates 'runoff' with 'quickflow'. In catchment hydrology, *runoff* (often used synonymously with streamflow, *Q*, as measured at the catchment outlet) conventionally comprises two components with distinct sources and response times:

- *Stormflow* (*Qs*): the event-driven ('direct' flow or *quick flow*) response that reaches the river channel rapidly via overland flow, *and* shallow subsurface pathways
- *Baseflow* (*Qb*): the delayed contribution from groundwater and deeper subsurface storage (sometimes termed *delayed flow* when contrasted with quick flow).

Conflating 'runoff' (i.e. total streamflow) with 'quick flow' (i.e. stormflow only) excludes baseflow, and would, therefore, greatly underestimate total discharge. Likewise, equating 'runoff' with overland flow in Meason et al.'s Figure 1 ignores the dominant role of rapid shallow subsurface runoff in stormflow generation in forested catchments as well as that by the slower subsurface flows that sustain baseflows. Further, Meason et al. variously define groundwater as 'water stored below the soil' (their Figure 1) and 'underground water' as 'soil water, vadose zone water, or groundwater' and 'subsurface' water as 'vadose zone free-draining water and shallow groundwater' (p. 28).

In reality, groundwater is restricted to saturated conditions in which all pores are filled with water – regardless of the depth at which this occurs – while groundwater flow occurs under the influence of gravity and (positive) pressure gradients, thereby primarily maintaining the baseflow component of streamflow. By not explicitly including baseflow as a major component of total streamflow, Meason et al. would greatly underestimate the importance of their 'stream water' component, while at the same time overestimating the importance of their 'subsurface water' component commensurately (e.g. in their Figure 6).

Instead, the correct conceptual representation within the catchment water balance equation should be:

$$Q = Qs + Qb = P - ET - \Delta S - L$$

where *P* is precipitation, ET evapotranspiration (itself the sum of interception loss, transpiration and evaporation from the forest floor), ΔS the change in soil- and groundwater storage, and *L* is catchment leakage (i.e. subterranean water leaving the catchment boundary – often unrecorded). All values are conventionally expressed in millimetres of water per unit time (month, season, year etc).

Why this matters

Needless to say, accurate definitions are central to hydrological science, as imprecise terminology can obscure important processes, complicate comparisons with previous studies, and reduce the reliability of catchment-scale water balance interpretations. Also, lack of rigour in definitions hinders the correct understanding of research findings by non-specialists, risking additional confusion and misinterpretation instead of these 'data-driven' findings helping to 'dispel commonly-held beliefs' about pine water use and catchment water storage and release as claimed by Meason et al.

The paper claims that across the five key sites, ~74% of all rainfall events produced a measurable change in soil moisture content at 1 m depth (their Figure 5), even for small rainfall events (<2 mm; p. 28). This claim is somewhat problematic in that it is hard to envisage a physical mechanism by which such small events can 'bypass' pine forest canopies and litter layers where the joint storage capacities already exceed the rainfall amount (Putuhena & Cordery, 2000; see Figure 1), let alone that such small amounts can subsequently activate the near-saturated macropore flow required to reach a depth of 1 m (Cheng et al., 2018).

Furthermore, this infiltrated water may not contribute to groundwater recharge or streamflow, as it can still be lost by transpiration. Numerous studies have demonstrated that tree roots access deeper soil water when topsoil moisture becomes limiting (Jackson et al., 1983; Teskey & Sheriff, 1996; Beets & Beets, 2020; see Figure 2).

Erroneous claims and lack of rigorous review of earlier studies

The Meason et al. paper asserts that several misconceptions exist regarding the hydrological impact of *P. radiata* forests, including the claim that canopy interception is 'commonly reported' to amount to ~42% of rainfall (p. 31), without supporting this with a reference. Only one study has reported an interception loss of this magnitude – 49% for a pine stand in Otago (Fahey, 1964). All other published studies, both in New Zealand (Rowe, 2003) and internationally (Huber & Iroumé, 2001) report much lower interception losses for *P. radiata* (12%–35%).

Furthermore, the paper overlooks several previous rigorous studies on tree water use that provide important context. These studies (see Figure 3) have documented tree transpiration and interception loss for different species and environmental conditions within New Zealand. By not engaging with these studies, Meason et al. missed an opportunity to compare their own results with the broader body of evidence, to validate the methodology used, and to highlight where the contributions align with – or diverge from – existing knowledge. To simply state (p. 29) that the much lower values of forest ET obtained presently were likely because the Forest Flows project used 'more direct measurements as well as process-based modelling' does not do justice to the considerable body of sound evidence from previous work.

Meason et al. further criticise previous studies for failing to measure 'subsurface water', implying that this important hydrological component was neglected. However, apart from the fact that their claim is incorrect (see below), their own methodology for quantifying subsurface flows is not clearly described and may be conceptually flawed as noted above. From

Figure 2: Mature pine trees can grow deep roots that allow them to take up soil water from deeper layers when the surface soil dries out (after Watson and O'Loughlin, 1990)

the description provided, it appears that the reported values for 'subsurface water' were derived through modelling or indirect estimation, a practice common to many prior studies. As such, the claim that earlier work 'overlooked' subsurface flows is simply incorrect.

Without clear documentation of measurement methods, it is difficult to assess whether the approach used by Meason et al. provides any improvement over earlier work, or whether their critique of earlier studies is justified. However, the sum totals of 'tree water

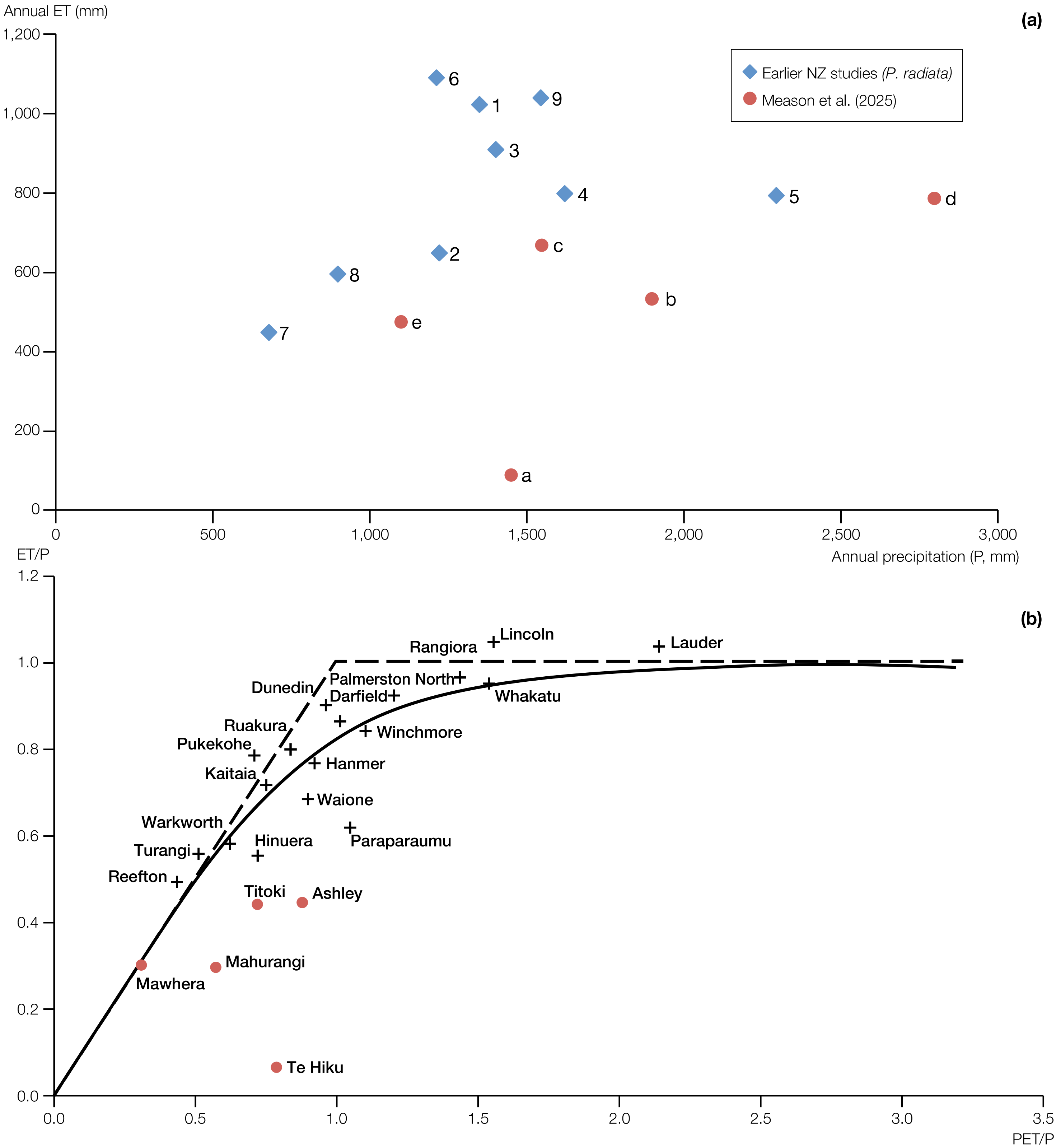

Figure 3: Annual ET totals for the five *P. radiata* plantations in Meason et al. (2025) (indicated in red: [a]Te Hiku; [b]Mahurangi; [c]Titoki; [d]Mawhera; [e]Ashley) versus (a) results from earlier New Zealand studies ([1]Pearce et al., 1987; [2]Fahey & Watson, 1991; [3]Whitehead & Kelliher, 1991a, [4]1991b; [5]Rowe & Pearce, 1994; [6]Duncan, 1995; [7]Arneth, 1998; [8]Fahey et al., 2001; [9]Beets & Oliver, 2007), and (b) plotted in 'Budyko space' against results for 18 sites with mixed land cover across New Zealand (adapted from Woods et al., 2006). PET = Potential Evapotranspiration

use', 'stream water' and 'subsurface water' in their Figure 6 exceed 100% for all but the driest catchment (range: 112%–127% of incident precipitation), despite the already noted likely underestimation of the first two components. This strongly suggests that Meason et al. greatly overestimated subsurface flows or even mixed up subsurface 'storage' with 'flow'.

Meason et al. rightly state that not taking deep leakage losses into account will lead to overestimated ET. However, the claim that earlier New Zealand studies failed to consider subsurface flows in catchment water balance analyses is not correct. In fact, several early investigations explicitly incorporated leakage as a key element in their water balance frameworks (Pearce et al., 1976, 1982, 1984; Dons, 1987; Rowe & Pearce, 1994; Beets & Oliver, 2007). These studies recognised that leakage plays an important role in closing the water balance.

Ignoring this body of earlier work gives a misleading impression of the available regional scientific literature and underestimates the progress already made in addressing this component of the water cycle. For instance, Pearce et al. (1982) derived an annual leakage loss of ~195 mm for several small (4.8–8.2 ha) forested catchments in Big Bush State Forest (South Nelson), which reduced to ~40 mm for a larger (20 ha) catchment. Similarly, the order of magnitude of leakage losses inferred early on for small catchments near Reefton, north Westland (Pearce & Rowe, 1979) was confirmed by subsequent detailed hydrogeological work (Gabrielli et al., 2018).

Lastly, differences in deep leakage between catchments matter much less in the context of paired-catchment experiments in which streamflow from a 'control' catchment is linked to that from a nearby 'treatment' catchment through regression ('calibration' equation; Fahey & Jackson, 1997). This is because any inherent differences between the catchments (including leakage) are incorporated in the calibration equation (Hewlett et al., 1969).

Assuming no changes in leakage over time, it follows that *changes* in streamflow and ET inferred from paired experiments involving conversion of grassland or shrubland to pine are robust. This is confirmed by the observation that reductions in streamflow following such land-cover conversions closely mirror the development of the pine canopy over time, including the effects of later thinning operations (e.g. Fahey & Payne, 2017; Hughes et al., 2020).

Greatly underestimated tree water use

The tree water use (transpiration + interception?) values reported in the Meason et al. paper (25% of annual rainfall on average) are substantially lower than previously published values for *P. radiata* in New Zealand (average ~64 ± 15% standard deviation, SD; N = 9) that were based on a range of measurement techniques and included corrections for deep leakage losses where applicable (see Figure 3a in this paper).

The Meason et al. estimates are also well below average annual ET for *P. radiata* across the globe (~63% ± 17% SD of annual rainfall; Tor-ngern et al., 2018). A similar result (i.e. substantial underestimation of ET/P for four out of five sites) is obtained when plotting the Meason et al. data in a diagram that illustrates the influence of variations in site water availability (i.e. precipitation excess) and evaporative conditions (represented by potential evapotranspiration, PET; see Figure 3b).

Evidence from (quasi) paired-catchment studies in New Zealand has consistently shown that ET estimates for grassland and pine forest are broadly comparable to direct measurements of transpiration and interception, provided that leakage is properly accounted for (Rowe, 2003). Further, leaf area related differences in interception losses in combination with rainfall largely explain differences in total water use between pine and pasture, as demonstrated amongst others by Beets and Oliver (2007). Their study showed that over a rotation, ET averaged around 60% of rainfall, but reached 90% in a drought year when leaf area was high and trees switched to water uptake from deeper layers.

Moreover, Fahey et al. (2001) and Swanson (1981) reported sapflow-based transpiration amounts equivalent to 42% and 74% of annual rainfall in 18- and 26-year-old *P. radiata* stands located in Canterbury (P = 900 mm year^{-1}) and Rotorua (P = 1,340 mm year^{-1}), respectively. Similarly, Arneth (1998) reported an ET equivalent to 66% of annual rainfall for an 8-year-old *P. radiata* stand at Balmoral in Canterbury (P = 680 mm year^{-1}) using a micrometeorological approach.

Taken together, this body of evidence indicates that the total water use (transpiration + interception?) estimates reported by Meason et al. are uncharacteristically low. It is tempting to explain this apparent underestimation of ET by Meason et al. failing to include the interception component (~25% of P for most of their sites), but the absence of a clear methodological description would render this rather hazardous. In addition, this would increase the already noted discrepancy between precipitation inputs and losses of water via evaporation and flows (their Figure 6) even more.

Conclusions and implications

Meason et al. derived low evapotranspiration estimates that we consider to be incorrect, given that they are inconsistent both with direct estimates of pine forest ET using a range of techniques and estimates from catchment water balance studies that include deep leakage losses. Likewise, their amounts of 'subsurface' water relative to 'stream water' appear to be greatly overestimated for four out of five sites given that the sum totals of the main water budget components exceed amounts of incident precipitation.

The generalisation of findings by Meason et al. to *Pinus radiata* forests across New Zealand is also invalid because leaf area driven rates of water use that depend on stand age, silvicultural management and harvesting were not addressed (cf. Kelliher et al., 1990). It cannot be excluded, therefore, that the curious finding of the lowest interception loss (9% of rainfall) coinciding with the lowest site rainfall (Ashley) reflects the characteristics of the stand in question. Generally, the highest relative interception fractions are reported for low-rainfall sites and vice versa (Roberts, 1999; Huber & Iroumé, 2001).

In conclusion, we maintain that instead of offering 'new insights' into the water use of *P. radiata* and the release of water by pine-forested catchments, Meason et al. have largely created new myths by greatly underestimating tree water use and overestimating subsurface flows. The Forest Flows team will need to go back to the drawing board, correct their hydrological concepts, and re-analyse their findings accordingly. Until then, in our view readers of Meason et al. had best rely on the previously published studies highlighted in the above.

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