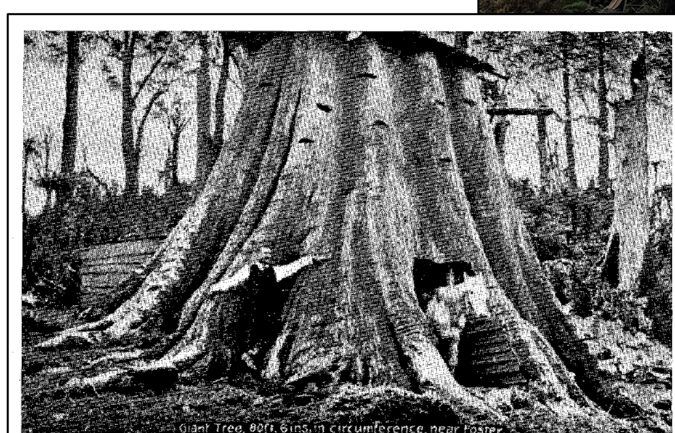
Post-fire changes in streamflow explained by forest self-thinning behaviour

Assaf Inbar[1], Richard Benyon[1], Raphaël Trouvé[1], Patrick Lane[1], Shane Haydon[2], and Gary Sheridan[1]

[1]School of Ecosystem and Forest Sciences, Faculty of Science, The University of Melbourne, Parkville, Victoria
[2]Melbourne Water Corporation, Melbourne, Victoria

Eucalyptus regnans

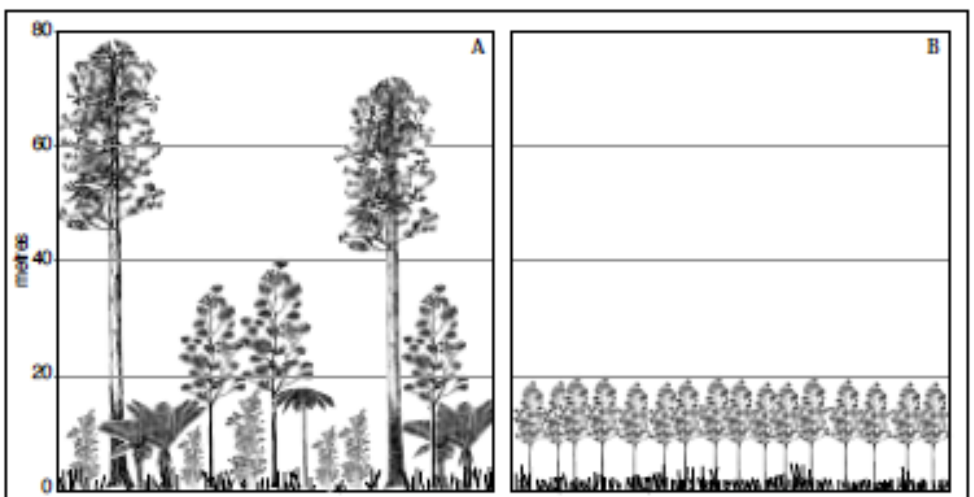
- *Eucalyptus regnans* (mountain ash) is the tallest angiosperm on earth
- Native to the temperate region of Southeastern Australia
- Can grow to ~100m tall
- Obligate seeder – seedlings require stand-replacing-fire to germinate
- Stand replacing fires in these forests occurs every 80-150 years
- Covers ~50% of Melbourne's water supply catchments, but provide ~80% of it's water



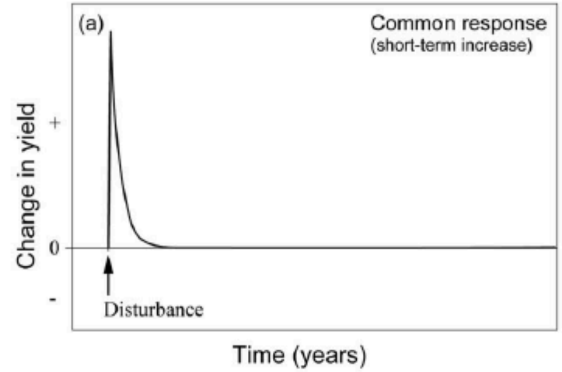
Ashton, D. H. (1975). *Australian Journal of Botany*, *23*(6), 867–887.

Effects of wildfire on water yield

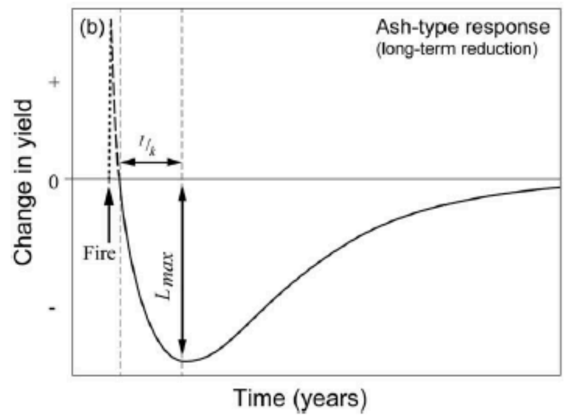
Stand replacing fires often cause a significant long-term reduction in streamflow from catchments covered by a large proportion of *E. regnans* forests. The relationship between water yield and forest age was generalized by George Kuczera** in 1987 (*The Kuczera curve*)



Schematic structure of an Old-growth (A) and regrowth (B) E. regnans stands. From: Vertessy, R. A., Watson, F. G. R., O'Sullivan, S. K., et al (1998). Industry Report No. 98/4. Clayton, Melbourne.



From: Brookhouse, M. T., Farquhar, G. D., & Roderick, M. L. (2013). *Water Resources Research*, *49*(7), 4493–4505.



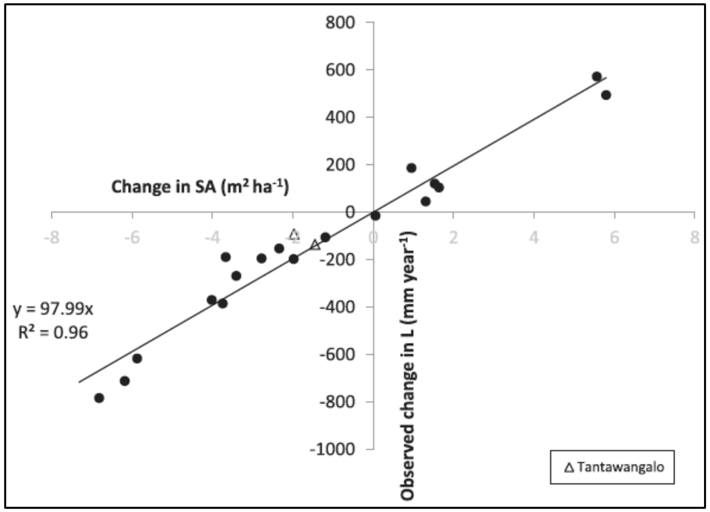
The Kuczera curve

This phenomenon was suggested to be the result of the higher water use of the regrowth trees compared to their old-growth counterparts

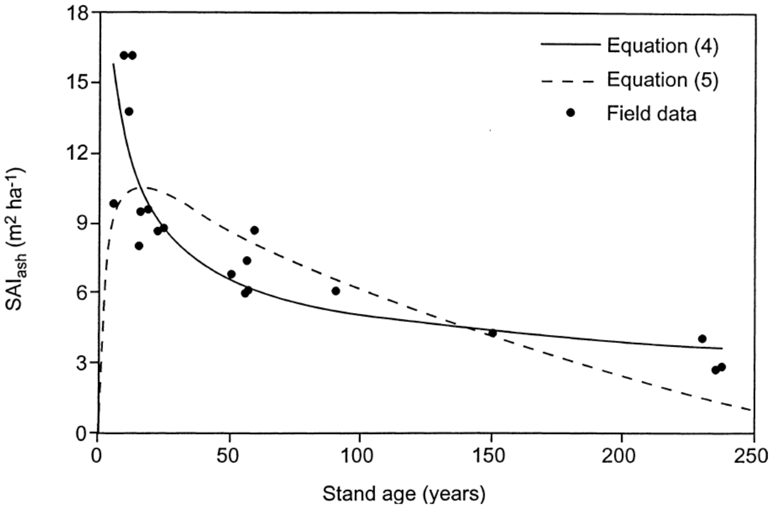
***Kuczera, G. (1987). Journal of Hydrology, 94(3–4), 215–236.*

Forest structure and Sapwood area

- Stand sapwood-area index (SA) was found to be a good predictor for evapotranspiration (ET)
- The relationship between sapwood area with forest age had been used in some hydrological models that predict streamflow from Melbourne water's catchments
- This approach is empirically-based, and misses a mechanistic understanding of how forest structural changes affect the relationship between sapwood-area and age



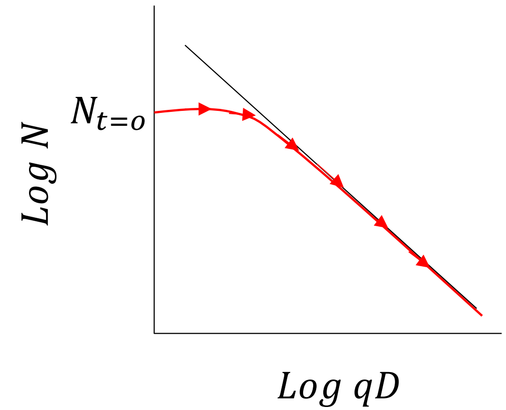
Benyon, R. G., Lane, P. N. J., Jaskierniak, D., Kuczera, G., & Haydon, S. R. (2015). Water Resources Research, 51(7), 5318–5331.



Vertessy, R. A., Watson, F. G. R., & O'Sullivan, S. K. (2001). *Forest Ecology and Management*, *143*(1–3), 13–26.

Forest structure

- Sapwood area is a forest structure attribute and can change with environmental conditions
- We argue that modelling forest dynamics (and by that decoupling the relationship between sapwood-area and age) can be beneficial for hydrological predictions from single aged forests under future climate



The self-thinning line

$$\log N = a \log qD + b$$

N – Stocking density
qD – Quadratic mean stem diameter
a and b – Site & Specie-specific parameters

- The *self thinning line* is a power-law equation used in ecology/silviculture that represents the maximum number of trees (N) for a given size that can be stocked per unit area in an even-aged stand (Reineke 1933)
- Implicitly incorporates tree-level competition and mortality
- Tree diameter in a stand that starts with a given N (at time t=0) will keep increasing until it reaches the self-thinning line
- Beyond that point, mortality driven by *competition for resources* will drive the changes in N

Research questions

Q1: Can we use the self thinning line to predict the post-fire pattern in SA and streamflow behavior with forest age?
And if so, what are the parameters with the largest influence?

Q2: Can we predict the change in streamflow by modelling competition of individual trees?

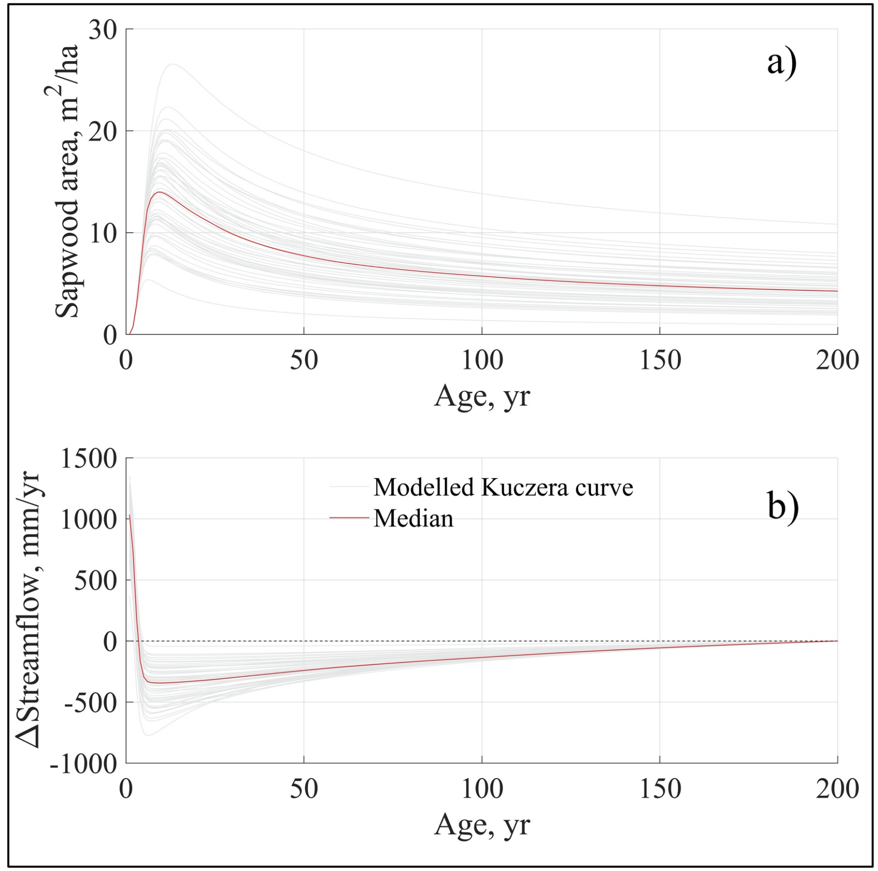
Methods

- For Q1, we used a very simple growth model and the self-thinning line for tree mortality to predict the trend of change in streamflow after a stand-replacing fire.
- For Q2 we used a similar growth model, but tree mortality was driven by competition for light and water (only in young age when roots are shallow).

Results: Q1

> **The self-thinning line**
>
> $$\log N = a \log qD + b$$
>
> N – Stocking density
> qD – Quadratic mean stem diameter
> a and b – Site & Specie-specific parameters

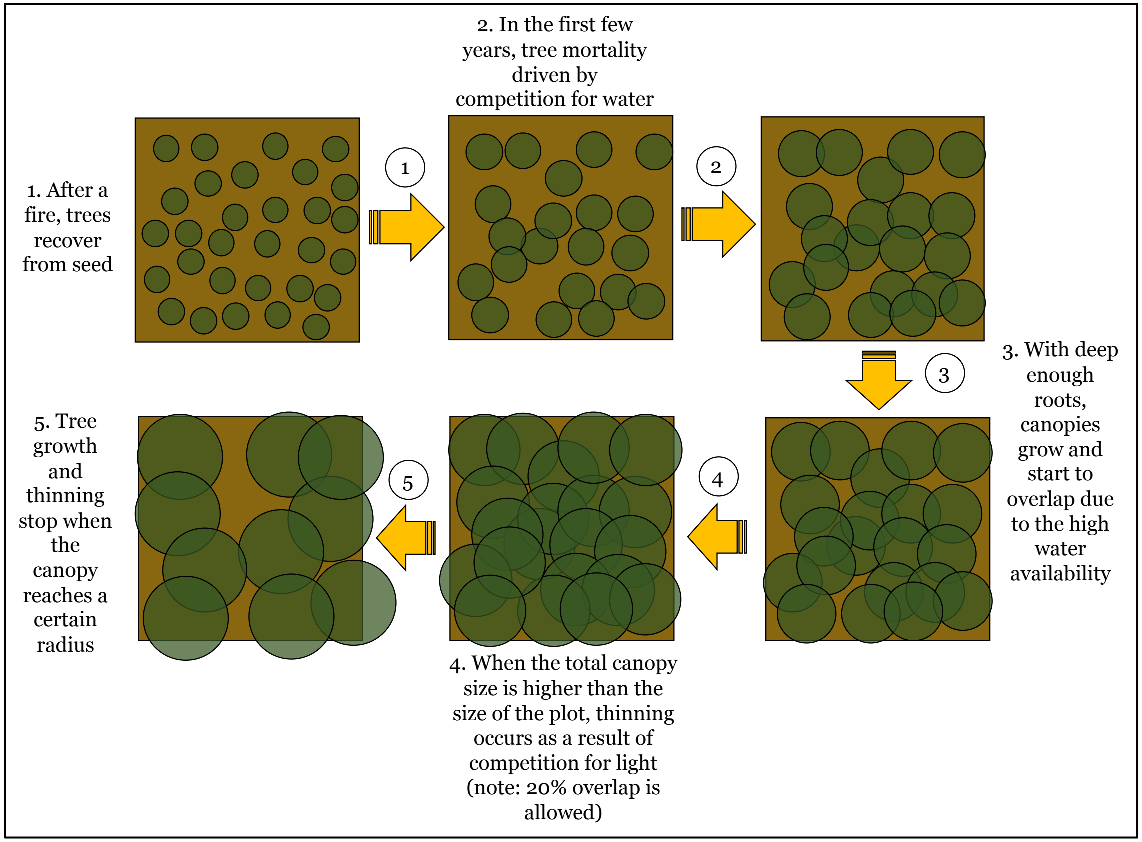
- Random parameters for the self-thinning line (around the mean values for *E. regnans* reported in Trouvé et al. 2017)) and initial stocking ($N_{t=0}$ trees/ha) were chosen from a normal distribution
- Both the pattern of change in sapwood-area with age and the Kuczera curve emerge from the model
- The model is sensitive to the parameters of the self-thinning line and the initial stocking, which reflects regeneration success



- These can explain the variability in the streamflow behavior that were observed by Kuczera and others

A simple tree-level competition model

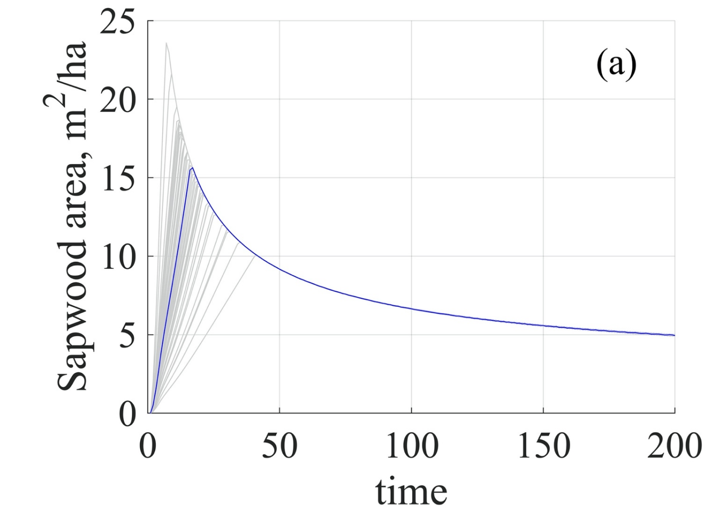
- A conceptual model for forest stand development
- Simple tree growth and mortality
- Assumes all trees are the same size with no understory
- Grows tree diameter, and canopy dimensions are then calculated using a generic allometric equation

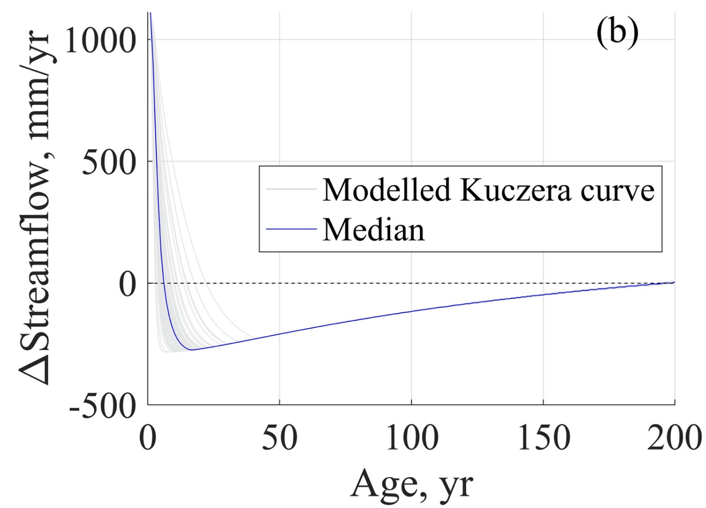


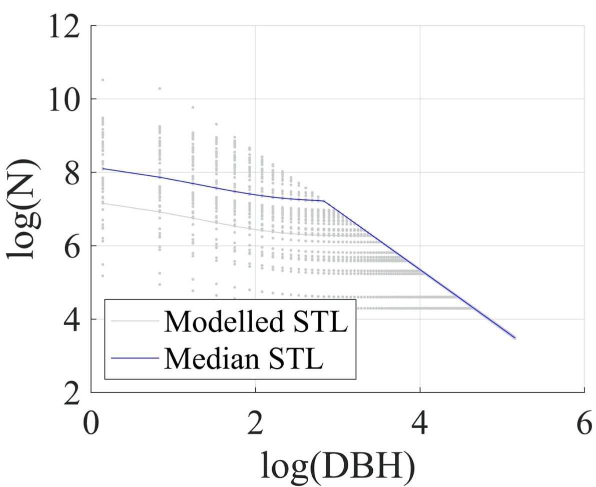
- Tree mortality occurs when: total crown area > plot area
- 50 model simulations were conducted with random initial stocking density chosen from a lognormal distribution

Results: Q2

- Self-thinning line, sapwood area as a function of age and the Kuczera-type streamflow reduction emerge from the model that includes tree-level competition for resources during recovery
- Decrease in streamflow not as high as predicted by the Kuczera curve (~-600 mm/yr deficit at the peak)







- The parameters for the self thinning line are similar to those typical to *E. regnans* forest

Summary & conclusions

- This preliminary work investigates the possibility of using a well-known ecological/silvicultural theory for ecohydrological predictions
- We show that the self-thinning rule can be used to explain the post-fire hydrological behavior of catchments that are covered by even aged *E. regnans* forests (Kuczera 1987), and possibly other species
- The self thinning line is an emergent property of tree-level competition for water and light during recovery
- Recovery success and the parameters of the self-thinning line can be used to explain some of the inherent variability in the Kuczera-type hydrological response
- More research is required as to the possible effect of climate change on forest structure (i.e., growth and mortality) and how it might influence water yield into the future

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