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Predicting the water use of *Eucalyptus nitens* plantation sites in Tasmania from inventory data, and incorporation of water use into a forest estate model

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ABSTRACT

The aim of this work was to derive a function predicting annual water use of *Eucalyptus nitens* plantations from basal area data, and to incorporate this function into an existing forest estate wood-flow scheduling model to allow assessment of the impacts of plantation management simultaneously on wood production and water use.

Annual plantation water use was measured in five plots in four adjacent *E. nitens* plantations 1–11 years after establishment in the Florentine Valley, Tasmania, Australia, over three years from 2008 to 2010, using continuous measurements of transpiration, canopy interception and soil evaporation (the components of plantation water use). Plantation water use ranged from 545 mm yr^{-1} in a 1-year-old plantation, to 1052 mm yr^{-1} in an unthinned 9-year-old plantation. Thinning (>50% basal area reduction) reduced plantation water use by around 30%.

An empirical model was developed from the Florentine data to predict annual water use of *E. nitens* plantations from their basal area. This model explained 64% of the variability in water use in the input dataset containing data from both thinned and unthinned plantations. Inclusion of annual rainfall data improved the explanatory power of the model to 78.5% of the variability in water use. The model predicted annual water use of 791 mm for a 6-year-old *E. nitens* plantation at Forestier, Tasmania in 2011; site water use measured for that year was 792 mm.

The basal area:water-use relationship was included in Forestry Tasmania's existing forest estate model, and used to estimate water use and available wood volume for 1532 ha of *E. nitens* plantations in the Florentine Valley over a 90-year period and for a range of hypothetical scenarios. Optimised harvesting schedules were produced by incorporating water-use constraints into the forest estate model.

1. Introduction

There is an increasing expectation that plantation owners will consider and manage the water use of their plantations to protect downstream water users and aquatic ecosystems. Water management is also often necessary for accreditation of wood production or to comply with water management plans.

The water use of a vegetated site comprises transpiration, soil evaporation and canopy interception (some authors refer to water use as evapotranspiration). Each of these components of site water use is dependent on vegetation characteristics, meteorological variables and soil characteristics, and here we use the term 'plantation water use' to refer to the total water use of a plantation site. Water-use values for plantations, native forest and pasture have been measured in a number of short-term experiments (Benyon and Doody, 2004; Feikema et al., 2007; Forrester et al., 2010; Hatton and Vertessy, 1990; McJannet et al., 2000), estimated using process models such as 3PG (Feikema et al., 2007), CABALA (Battaglia et al., 2004) and Promod (Sands et al., 2000), and inferred from paired-catchment studies (Bren and Hopmans, 2007; Cornish and Vertessy, 2001). The impacts of plantation establishment on the water use of land previously carrying pasture or native forest are thus reasonably well understood. In general, where pasture is planted with trees, water use increases (Bosch and Hewlett, 1982; Vertessy, 2001: Bren et al., 2006; Best et al., 2003). Where native forest is replaced with plantation, water use may increase or decrease, depending on the species and density, age and health of the original forest and the growth rate and management regime

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of the plantation (Bren and Hopmans, 2007; Bren et al., 2006; Cornish and Vertessy, 2001).

What is currently lacking is the ability to consider plantation water use when assessing plantation management scenarios, that is, the ability to manage plantations for wood production in a way that minimises changes in water use over time, thereby minimising impacts on downstream water users. A tool that integrates knowledge of plantation water-use values with data on plantation locations, species and density, growth rates, management regimes, management objectives and constraints would allow identification of management scenarios that optimise financial returns from wood production while minimising impacts on water resources.

Forest estate models are mainly used by forest owners to estimate volumes of standing and harvested wood through time. They are spatial forest management planning systems that enable managers to schedule their activities based on constraints such as maximum sustainable yields, and aid decision making by allowing the effects of different management scenarios on wood production and consequent income to be compared (McLarin et al., 2006). Advantages of inclusion of plantation water use in forest estate models include:

- Most sizeable forest companies already have forest estate models.
- Forest estate models represent the best available source of information about plantations comprising a forest estate, including species, structure, management and growth. The quality of this information is subject to continuous improvement as new data are incorporated.
- Forest estate models are optimisation tools that allow a range of scenarios to be assessed under a variety of constraints, comparing wood production, product mixes, financial outcomes and residual standing volumes from various scenarios.

Forestry Tasmania's forest estate model, which uses Remsoft's Spatial Planning System, including the Woodstock module, is a tool that could be used to compare plantation water use, wood production and economic returns for different management scenarios. The model performs calculations for each defined planning unit (usually a coupe), but can provide analyses for a plot of land, property, compartment, or cluster of coupes, or for all the coupes in a catchment, district or entire forest estate, by combining results from multiple planning units. Inventory data, growth models, information about species, age, stocking, management regimes, site quality, and the location and extent of each planning unit, are used by the model to generate estimates of basal area for the planning unit over time (Fig. 1). Incorporation of production objectives and constraints then allows scheduling of harvesting events, and calculation of wood volumes harvested, residual basal area and residual standing volume. Inclusion of financial information allows production of estimates of the value of sales and the value of standing timber.

In this work, we explore inclusion of a basal area:water-use function in this forest estate model, to allow water use, wood production and income to be assessed simultaneously, and to allow changes in water use to be used as a constraint to harvesting scenarios. Water-use components were measured over several years in plots in adjacent *Eucalyptus nitens* plantations of different ages in the Florentine Valley, Tasmania. The data were used to create water-use functions based on basal area, with these functions then being tested in a *E. nitens* plantation at Forestier in eastern Tasmania.

Previous studies found links between forest water use and growth parameters such as sapwood area, leaf area and basal area (Forrester et al., 2010; Macfarlane et al., 2010; Roberts, 2001; Vertessy et al., 1995; Vertessy et al., 2001). This study uses the link between basal area and water use, since basal area estimates are already generated by forest estate models.

2. Materials and methods

2.1. Description of experimental sites

Water-use studies were undertaken in five plots in four adjacent *E. nitens* plantations of different ages in the Florentine Valley (Latitude 42°36′28″S, Longitude 146°28′8″E), and in one plot at Forestier (Latitude 42°56′24″S, Longitude 147°54′8″E). *E. nitens* was selected for this study because it is a species widely planted in Tasmania for which little water-use data have been collected. The sites measured had *E. nitens* growing in uniform stands with sparse understoreys, which reduced the complexity of measurement and interpretation. Florentine Valley plantations were selected because there were a number of plantations of different ages growing in close proximity on uniform soil and terrain. Florentine Valley plantations rarely experience significant water limitation because annual rainfall typically exceeds annual potential evaporation, while the Forestier validation site was selected as a water-limited site because annual potential evaporation frequently exceeds annual rainfall. Table 1 describes the features of each plot and plantation, including age, stocking, and management regime.

The Florentine plantations are located near Eden Creek Rd, approximately 145 km north-west of Hobart at around 400 m above sea level. The plantations are on deep, well-drained red/brown ferrosols derived from Jurassic dolerite, with some limestone outcrops (Grant et al., 1995). The soil has low erodibility and good fertility. The current rotation of *E. nitens* was planted between August 1999 and October 2007 at densities of around 1100 stems per hectare, with the sites ripped and mounded prior to planting and with weed and pest control applied as necessary. The sites were previously occupied by plantation. The plantations are managed to produce sawlogs, with pruning and thinning as part of the management cycle.

The long-term average rainfall at Maydena (the nearest weather station to Eden Creek Rd) is 1200 mm yr^{-1} (Bureau of Meteorology, www.bom.gov.au). Maydena is located 21 km south east of the Florentine field site at an altitude of 281 m. Potential evaporation is around 900 mm yr^{-1} (as determined by Silo Data Drill, Queensland Department of Environment and Resource Management). Silo Data Drill accesses grids of data interpolated from point observations by the Bureau of Meteorology.

The Forestier plantation is located near Hylands Rd, approximately 45 km east of Hobart at around 315 m above sea level. The plot is on Jurassic dolerite, and boulders and cobbles are common on the surface (30–80%), and in the soil matrix (50–90%). The soil is well drained loam over clay, with moderate potential for erosion and good fertility. The *E. nitens* plantation was established in June 2005 at a density of 1117 stems per hectare, with the site previously being occupied by native forest. Spot cultivation was used to prepare the soil because the site is stony. The plantation is managed for pulp production and is not pruned or thinned.

The long-term average rainfall at Dunalley (the nearest weather station to the Forestier plantation) is 700 mm yr^{-1} (Bureau of Meteorology, www.bom.gov.au). Dunalley is 9 km to the north west of Forestier at an altitude of 12 m. Potential evaporation is around 1042 mm yr^{-1} (as determined by Silo Data Drill).

2.2. Environmental variables

Automatic weather stations (Pacific Data Systems AWS–100) were installed in clearings adjacent to the plantations to record rainfall, air temperature, wind speed and direction, relative humidity, soil temperature and soil moisture at 15 min intervals.