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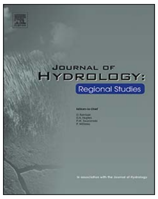

Hydrological response to bauxite mining and rehabilitation in the jarrah forest in south west Australia

Andrew H. Grigg[a,b]

[a] Environmental Department, Alcoa of Australia, Australia
[b] Huntly Mine, PO Box 172, Pinjarra, WA, 6208, Australia

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ABSTRACT

Study region: Jarrah forest in south west Australia.

Study focus: The hydrological response to bauxite mining in the jarrah forest could differ from other land uses such as timber harvesting or clearing for agriculture, since mining involves excavation of the upper regolith in addition to changes in forest cover due to clearing and subsequent rehabilitation. Three catchments, one subject to mining, a second subject to an intensive forest thinning treatment and an untreated control were monitored for streamflow, rainfall, groundwater and leaf area index over a 36-year period.

New hydrological insights for the region: Mining caused a peak streamflow response of 225 mm or 18% of rainfall, before returning to pre-disturbance levels 11 years after mining commenced. Streamflow changes were closely associated with changes in a groundwater discharge area in the valley floor. Changes in groundwater level, in turn, were related to rainfall and leaf area index, and these effects did not differ between mine rehabilitation and unmined catchment areas. The streamflow response to mining could not be distinguished from the intensive thinning treatment in this study, or from clearfelling or clearing for agriculture reported elsewhere in the jarrah forest. The results indicate that shallow subsurface flow processes, considered to dominate streamflow generation in jarrah forest catchments, do not extend beyond the valley floor and immediately adjacent slopes which were not disturbed by mining.

1. Introduction

The deep highly weathered lateritic profiles that support jarrah (*Eucalyptus marginata*) forests in south-west Western Australia are capable of storing a large proportion of annual rainfall (Schofield et al., 1989). The store of soil water is exploited by the extensive rooting system of jarrah to depths of 40 m or more (Dell et al., 1983) and evapotranspiration forms the major loss component of the jarrah forest water balance, estimated in catchment studies to exceed 90% of annual rainfall (Ruprecht and Stoneman, 1993). Hence, manipulation of forest cover has long been proposed as one option to influence catchment yields (Stoneman and Schofield, 1989) and numerous studies have been undertaken to determine catchment responses to forest harvesting activities (Ruprecht et al., 1991; Stoneman, 1993; Bari et al., 1996; Robinson et al., 1997; Kinal and Stoneman, 2011). In reviewing the impacts of land use practices in 27 catchment studies across the south-west of Western Australia, Bari and Ruprecht (2003) reported that clearing for agriculture led to permanent increases in yield of about 30% of annual rainfall in high rainfall (> 1100 mm) areas. Forest thinning in higher rainfall areas resulted in maximum streamflow increases of 8–18% of rainfall, depending on the degree of treatment. Streamflows returned to pre-treatment level after 12–15 years, matching vegetation recovery, or longer if regeneration is limited.

E-mail address: andrew.grigg@alcoa.com.au.

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The lateritic profiles also support extensive but discontinuous and shallow (3–5m) surface deposits of bauxite, which have been mined since the 1960′s (Hickman et al., 1992). Expansion of mining in the 1970′s raised concerns over its effects on the hydrology of the jarrah forest (Steering Committee, 1978) and a small number of empirical catchment studies investigating the effect of mining have been reported. Ruprecht and Stoneman (1993) found that mining of 16% of Del Park catchment in 1975–79 resulted in a peak yield increase of 8% of rainfall, followed by a return to pre-mine levels 12 years after the commencement of mining. Bari and Ruprecht (2003) reported larger peak responses in the Seldom Seen and More Seldom Seen catchments of 23% and 21% of rainfall, respectively, noting a good correlation between the increase in streamflow and the proportion of the catchment cleared for mining but not yet rehabilitated. Croton and Reed (2007) found peak increases of 200–250 mm/year, representing responses of 14–17% of rainfall, in a further two mined catchments. In all cases, a consistent pattern of an initial increase in flow followed by a return to, or below, pre-mining levels was observed. These patterns show similarities to the responses observed for other land use practices, however, short (1–3 year) pre-mining calibration periods or difficulties with suitable controls detracted from some of these studies and none went beyond a consideration of annual flow responses. Furthermore, Croton et al. (2005) claimed that a higher water use in young mine rehabilitation was necessary to obtain an acceptable match to streamflow in modelling studies. There remains, therefore, a need to understand in greater detail the effects of bauxite mining on hydrological processes than has been reported to date.

Concurrent with the effects of land use practices on streamflows in the jarrah forest has been the effect of a drying climate. The south-west of Australia has experienced a 15–20% decline in annual rainfall since the 1970′s and a growing number of once perennial streams in the higher rainfall parts of the forest are now seasonal (Petrone et al., 2010). Streamflow decline is observed as a step change in response to the occurrence of years of very low rainfall, reflecting a strong correlation between runoff as a proportion of rainfall and groundwater storage (Hughes et al., 2012). Catchment groundwater storage increases when rainfall exceeds a certain threshold but decreases in years when rainfall is below the threshold. Kinal and Stoneman (2012) reported a particularly dramatic drop in streamflow when groundwater declined below or ‘disconnected’ from the valley floor, highlighting an ‘amplifying’ role of groundwater in streamflow generation. When groundwater levels are well below the valley floor, even intensive forest thinning within a catchment can have no effect on streamflows (Kinal and Stoneman, 2011).

The aims of this study were to determine the hydrological response to bauxite mining and subsequent rehabilitation in the jarrah forest, and to compare the response to mining with the response to other land use practices. The study utilised three small jarrah forest headwater catchments over a combined experimental period of 36 years. One catchment experienced a 5-year period of mining and associated rehabilitation, a second was subject to an intensive thinning treatment, and a third acted as an untreated control. Comparisons were made between the mined catchment and the untreated control to determine the effects of mining independent of changes due to climate, while the intensively thinned catchment provided a comparison between a mining disturbance and an alternative land use practice that reduced catchment forest cover to an extent similar to the mined catchment but without excavation of the upper regolith. Detailed measurements of rainfall, groundwater, streamflow and changes in forest leaf area index (LAI), a key determinant of vegetation water use (Waring, 1983), were collected and are reported here.

2. Materials and methods

2.1. Geomorphology, climate and bauxite mining in the jarrah forest

The northern jarrah forest region of Western Australia occurs on the Darling Plateau, an elevated undulating landform developed predominantly on coarse-grained granites and granitic gneisses (Churchward and Dimmock, 1989). The basement rock has been weathered *in situ* to form deep (> 30m) lateritic profiles, the upper parts of which are enriched in sesquioxides of iron and aluminium. The surface horizon consists typically of gravels, sands and loams including a discontinuous indurated layer or duricrust, mostly in mid- to upper-slope positions, merging with the underlying mottled and pallid clay zones. The sandy gravels of the upper slopes become finer downslope, forming deep sands adjacent to the valley floor which in turn are typically dominated by loams and clay loams (Churchward and Dimmock, 1989). Root channels of lower bulk density extending vertically through fissures and discontinuities in the indurated layer and deep into the mottled and pallid clay zones (Dell et al., 1983) are a feature of the lateritic profiles, forming preferred flow paths for infiltrated rainfall and permitting rapid recharge of permanent groundwaters (Johnston, 1987).

The climate of the region is Mediterranean with winter-dominant rainfall (May to October) and a summer drought. Rainfall is greatest on the western margin of the jarrah forest and declines with distance inland. Historical annual average rainfall ranged from 1300 to 600 mm (Gentilli, 1989), however, the region has experienced a 15–20% rainfall reduction since the 1970′s and drought years are now more frequent (Petrone et al., 2010).

The alumina-rich duricrust and mottled zone materials constitute the bauxite ore removed by mining (Hickman et al., 1992). Alcoa of Australia (Alcoa) has been mining for bauxite in the northern jarrah forest since 1963 and presently clears and rehabilitates approximately 550 ha annually (Koch, 2007a). Alcoa's operations comprise a mosaic of shallow pits averaging 4 m in depth and around 20 ha in size distributed across a mining region and linked to a centrally-located crusher by a radiating network of haulroads. A detailed description of the mining process and rehabilitation prescriptions is provided in Koch (2007a). Briefly, the process involves harvesting and clearing of the native forest, stripping of topsoil and subsoil layers to expose any lateritic duricrust layer present, followed by blasting and extraction of the duricrust and underlying friable bauxite. Once ore has been removed, the pit is landscaped to form an undulating terrain while ensuring that surface water does not discharge from the pit into adjacent unmined areas. Ripping using a winged tine to an approximate depth of 1.5 m is undertaken to relieve compaction of the pit floor, the subsoil and topsoil are returned, and the surface ripped for a second time to approximately 0.8 m depth along the contour. This aids infiltration, reduces the