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Hydrological impact of two intensities of timber harvest and associated silviculture in the jarrah forest in south-western Australia

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SUMMARY

The hydrological impact of two different intensities of timber harvest and associated silviculture, one standard and the other more intensive, was investigated using a paired-catchment study in jarrah forest in south-western Australia. This study was undertaken during a period when average annual rainfall was below the long-term average and deep groundwater levels were declining. Following treatment, recharge increased and slowed the decline in deep groundwater levels in proportion to the magnitude of the initial reduction in vegetation density. However, neither treatment was sufficiently intense to reverse the continued decline in groundwater levels over the course of the study. Annual stream salinity did not increase in response to either treatment because saline deep groundwater did not rise following the treatments. Annual streamflow did not increase in either catchment for three reasons. Firstly, there was little additional net precipitation to the intermittent shallow perched groundwater system in the streamzone because the area remained untreated. Secondly, there was minimal additional throughflow to the perched groundwater system in the streamzone from upslope areas because the increased net precipitation in hillslope areas following treatment was used in replenishing the progressively increasing soil moisture deficit. Thirdly, because groundwater levels did not rise and hence there was little prospect for an increased discharge of saline groundwater or of an expanded deep groundwater discharge zone.

This study has demonstrated that the measures that were implemented to timber harvest and silvicultural methods to reduce the magnitude of the groundwater response and hence the risk of a transient increase in stream salinity are effective. If annual rainfall remains relatively low and deep groundwater levels remain at current levels or decline further, then the risk of an increase in stream salinity from either the standard or the more intensive harvest and silviculture will be low.

1. Introduction

Streamflow in the jarrah (Eucalyptus marginata Donn ex Smith) forest in south-western Australia consists primarily of throughflow with smaller proportions of overland flow, and groundwater flow (Stokes and Loh, 1982). Throughflow and overland flow are relatively fresh whereas groundwater is relatively saline in the lower rainfall parts of the forest. Consequently where groundwater contributes to streamflow it is also the major source of salt in streamwater. Hence stream salinity is largely determined by the volume and salinity of groundwater relative to the other streamflow components (Stokes and Loh, 1982).

Timber harvesting and associated silvicultural operations in the jarrah forest result in a temporary decrease in transpiration and interception leaving more water available for other hydrologic processes, including groundwater recharge and streamflow, until the forest regenerates to former levels (Borg et al., 1987a, 1988). An increase in groundwater recharge may lead to a rise in groundwater levels and, depending on the proximity of groundwater to the soil surface and the salinity of groundwater, an increased contribution of saline groundwater to streamflow. This in turn may result in a transient increase in annual stream salinity if the increased discharge of salt is not diluted by a corresponding increase in relatively fresh throughflow (Borg et al., 1987a, 1988).

The risk of an increase in annual stream salinity from timber harvesting and silvicultural treatments varies according to the degree of disturbance to the vegetation and the distribution of soil salt storage and groundwater levels in the jarrah forest (Schofield et al., 1989). Soil salt storage and depth to groundwater increase from west to east across the northern jarrah forest on a gradient inversely related to annual rainfall. Hence the lowest levels of salt storage and the shallowest depths to groundwater correspond with the region of highest annual rainfall near the western extent of the forest whereas the highest levels of salt storage and the greatest depths to groundwater correspond with the region of lowest

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annual rainfall near the eastern extent of the forest. To facilitate forest management, the jarrah forest was assigned to one of three zones which reflected the broad differences in salt storage and hydrology across the forest, and the risk of stream salinity from a disturbance to the forest (Loh and Stokes, 1981). The boundaries between the zones corresponded with isohyets based on the long-term average annual rainfall records until 1978 (Hayes and Garnaut, 1981), i.e., high (>1100 mm/y), intermediate (900–1100 mm/y), and low (<900 mm/y) rainfall zones. Areas in the intermediate rainfall zone are considered at highest risk of increasing stream salinity following a temporary reduction in vegetation density because salt storage is moderately high and groundwater may be sufficiently close to the soil surface to discharge saline water to streams. In the low rainfall zone, the risk of an increase in stream salinity from a temporary reduction in vegetation density is low despite the high salt storage because groundwater levels are well below the soil surface and streamflow results entirely from throughflow and overland flow.

Following a number of studies conducted in the 1970s to the 1990s on the impact of forest management practices on catchment hydrology in the jarrah and mixed jarrah and karri forest (Stokes and Batini, 1985; Borg et al., 1987a, 1988; Ruprecht et al., 1991; Bari and Boyd, 1993; Stoneman, 1993; Robinson et al., 1997) additional measures were implemented by forest managers to protect stream water quality in areas receiving less than about 1100 mm annual rainfall (Department of Conservation and Land Management, 1992). The measures, which include the retention of an undisturbed riparian zone and a minimum density of vegetation in space and time in the remainder of the catchment following harvest and silviculture, were incorporated into Forest Management Plan 1994–2003 (Department of Conservation and Land Management, 1994). These measures intend to limit the rise in groundwater levels and thus reduce the risk of a transient increase in stream salinity. Ministerial Condition 12-3 on Forest Management Plan 1994–2003 required the Department of Conservation and Land Management to monitor and report on the effectiveness of these measures in protecting water quality (Minister for the Environment Western Australia, 1992).

This study was initiated in response to Ministerial Condition 12-3 and aimed to quantify the impact of the standard harvest and silviculture that pertained to Forest Management Plan 1994–2003 on the hydrology of a small catchment in the intermediate rainfall zone of the jarrah forest. A more intensive harvest and silvicultural treatment was applied to a second small catchment as a comparison with the standard silvicultural treatment to provide information about the sensitivity of streamflow and groundwater response to the extent of temporary reduction in forest cover.

2. Hydrology of jarrah forest in the intermediate rainfall zone

The hydrology of the jarrah forest has been described in detail by Schofield et al. (1989) and the aspects pertinent to the intermediate rainfall zone are summarised below. Geomorphology and rainfall are key determinants of the hydrological processes in the jarrah forest. The jarrah forest occurs on the Darling Plateau which forms the south-western part of the Great Plateau of Western Australia (Churchward and McArthur, 1980). The basement rock of the Darling Plateau is Archaean granite and gneiss which has weathered *in situ* to form a lateritic soil profile which may be as deep as 50 m (Dimmock et al., 1974). The laterite profile typically consists of a surface horizon of gravels, sands, and loams, at times including duricrust, that merges with depth into mottled and pallid clays (Churchward and Dimmock, 1989). In the upper parts of the landscape, relatively more of the laterite profile remains intact whereas in the lower slopes and valleys, the profile has been eroded and overlaid with soils developed locally or transported from upslope. The topography of the study area is gently undulating with local relief generally varying from 50 to 100 m (Churchward and Dimmock, 1989).

The climate of the region is mediterranean with cool, wet winters and hot, dry summers. About 80% of the rainfall occurs in the 5 months from May to September (Hall et al., 1981). Annual rainfall is greatest near the western margin of the Darling Plateau and the south coast and follows a declining gradient inland (Gentilli, 1989). In the 1980s the range in average annual rainfall was about 1300–600 mm (Gentilli, 1989). Salt storage, streamflow and groundwater discharge are all strongly correlated with annual rainfall.

Average soil salt storage in the high rainfall areas is about 0.1 kg/m^3 and increases exponentially with decreasing average annual rainfall to about 5 kg/m^3 in the low rainfall areas (Stokes et al., 1980). Soil salt storage is highly variable locally but typically increases from hilltops to valley floors. The source of the salt is oceanic spray which is transferred by rainfall and dry fallout.

Shallow throughflow of ephemeral perched groundwater is the major source of streamflow. Throughflow occurs when rainfall infiltrates the permeable topsoil, perches on the underlying relatively impermeable clay horizon, and flows downslope to discharge to streams. Overland flow occurs in the near vicinity of streamzone areas that become saturated and is considered to be a relatively small proportion of streamflow. Deep permanent groundwater only contributes to flow when it is sufficiently close to the soil surface. Over the last 3 or 4 decades this has occurred frequently in the high rainfall zone whereas in the low rainfall zone permanent groundwater is too deep. In the intermediate rainfall zone groundwater has often been sufficiently close to the soil surface to contribute to streamflow.

In the past 3 or 4 decades, the proportion of annual rainfall that results in streamflow ranged from about 20% in the high rainfall zone to less than 1% in the low rainfall zone. Most rainfall is evaporated back to the atmosphere, principally as transpiration. A lesser amount is intercepted by foliage and subsequently evaporated. Groundwater recharge is greater in lower than in upper topographic positions but overall it is a small proportion of annual rainfall. A significant proportion of winter rainfall is stored in the soil. The soil–water store is depleted in the dry season when the loss by transpiration exceeds the addition by rainfall. Streamflow of lower-order streams is usually intermittent in the intermediate rainfall zone. Flow commences some time after winter rains have replenished the soil water deficit that accumulated over the previous dry season and seldom continues beyond late spring.

Stream salinity is determined by the relative proportions of groundwater, which is the main source of salt, and throughflow and overland flow which are relatively fresh. Over the past 3 or 4 decades, annual stream salinity has been highest in the intermediate rainfall zone where moderately saline groundwater discharging into streams is partially diluted by relatively fresh throughflow and overland flow. The lowest annual stream salinity has been in the low rainfall zone where the highly saline groundwater is too deep to discharge to streams. In the high rainfall zone annual stream salinities are low because groundwater salinity is low.

Stream salinity varies seasonally because of the variation in the relative proportions of throughflow and overland flow to groundwater discharge. Annual variation in stream salinity is due to the variation in throughflow and overland flow because of variation in rainfall, and also to longer-term changes in groundwater level which affect the relative contribution of groundwater to streamflow.

The introduced soil-borne fungal plant-pathogen *Phytophthora cinnamomi* Rands has infected areas of the jarrah forest, causing the decline and death of jarrah trees and susceptible midstorey and understorey species (Podger, 1972). Areas of forest affected