CHAPTER 4

Review of the Impact of Logging and Regeneration on the Hydrology of the Southern Forest of Western Australia

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Abstract

Research into both the short-term and long-term effects of logging in the southern forest of Western Australia on water quality and quantity began in 1973. Four major projects were undertaken.

Permanent clearing was shown historically to have led to increases in stream salinity in the intermediate and low rainfall zones (<1100 mm y^{-1}). Substantial increases in stream salinity following logging and regeneration were thought to be unlikely.

Vegetation cover returned to unlogged levels within 5 to 10 years for karri *(Eucalyptus diversicolor)* forest and 10 to 15 years of logging and regeneration for jarrah-marri (*E. marginata-E. calophylla*) forest. Groundwater levels rose for 2 to 4 years after logging and then started to decline. They should return to pre-logging levels by 13 years after logging and regeneration. Groundwater responses were much less in the low rainfall zone (<900 mm y^{-1}) than the intermediate and high rainfall zones (>900 mm y^{-1}). Stream salinities increased by 2 years after logging and regeneration and then declined. Stream salinity did not increase in the low rainfall zone. Stream sediment concentrations increased on catchments which had no stream buffer and were logged during winter. Sediment concentrations increased for 1 to 2 years following logging and then declined to pre-logging levels over the subsequent 3 years. Catchments which had a stream buffer and were logged during summer had no increase in sediment concentrations. Streamflow volumes increased for 2 to 3 years after logging and regeneration and then declined, and should return to pre-logging levels by about 12 years after regeneration. The increases in streamflow volumes were about 10 per cent of rainfall in the intermediate and high rainfall zones and less than 5 per cent of rainfall in the low rainfall zone.

Areas of continuing research and high priority additional research which is required are discussed.

PAST RESEARCH AND CURRENT KNOWLEDGE

In the late 1960s there was a move towards more intensive logging in the southern forest for various reasons (White and Underwood 1974; Bradshaw and Lush 1981; Borg *et al.* 1987b). Clearfelling (previously practised from the 1890s to 1940) was reintroduced in the karri *(Eucalyptus diversicolor)* forest and the successful regeneration treatments which occurred in the jarrah forests pre 1939 were re-instated. However, there was concern that clearfelling in the karri and intensive logging in the jarrah (*E. marginata*) forest might affect water quality (Environmental Protection Authority 1973; Forests Department 1973).

The Environmental Impact Statement on a proposed woodchipping industry in the Manjimup Woodchip Licence Area (Fig. 1) discussed risks to water quality (Forests Department 1973). It was decided that the industry should proceed but that research should be undertaken to quantify the effect on water quality (Environmental Protection Authority 1973).

In 1973 a Technical Steering Committee for Research on the Woodchip Industry was formed. The research program established by that committee is now the responsibility of the Steering Committee for Research on Land Use and Water Supply. This Committee is responsible to the State Government through the Coordinating Committee for Research on Land Use and Water Supply. Before establishing the research program no quantitative information was available on how logging affects stream salinity or stream sediment concentration. The research program was established to quantify both the short-term and long-term effects of the new logging operations.

The objectives of this paper are to (a) review research on the effects of logging on the hydrology of the southern forest, (b) describe research that is continuing and (c) describe high priority additional research that is required.

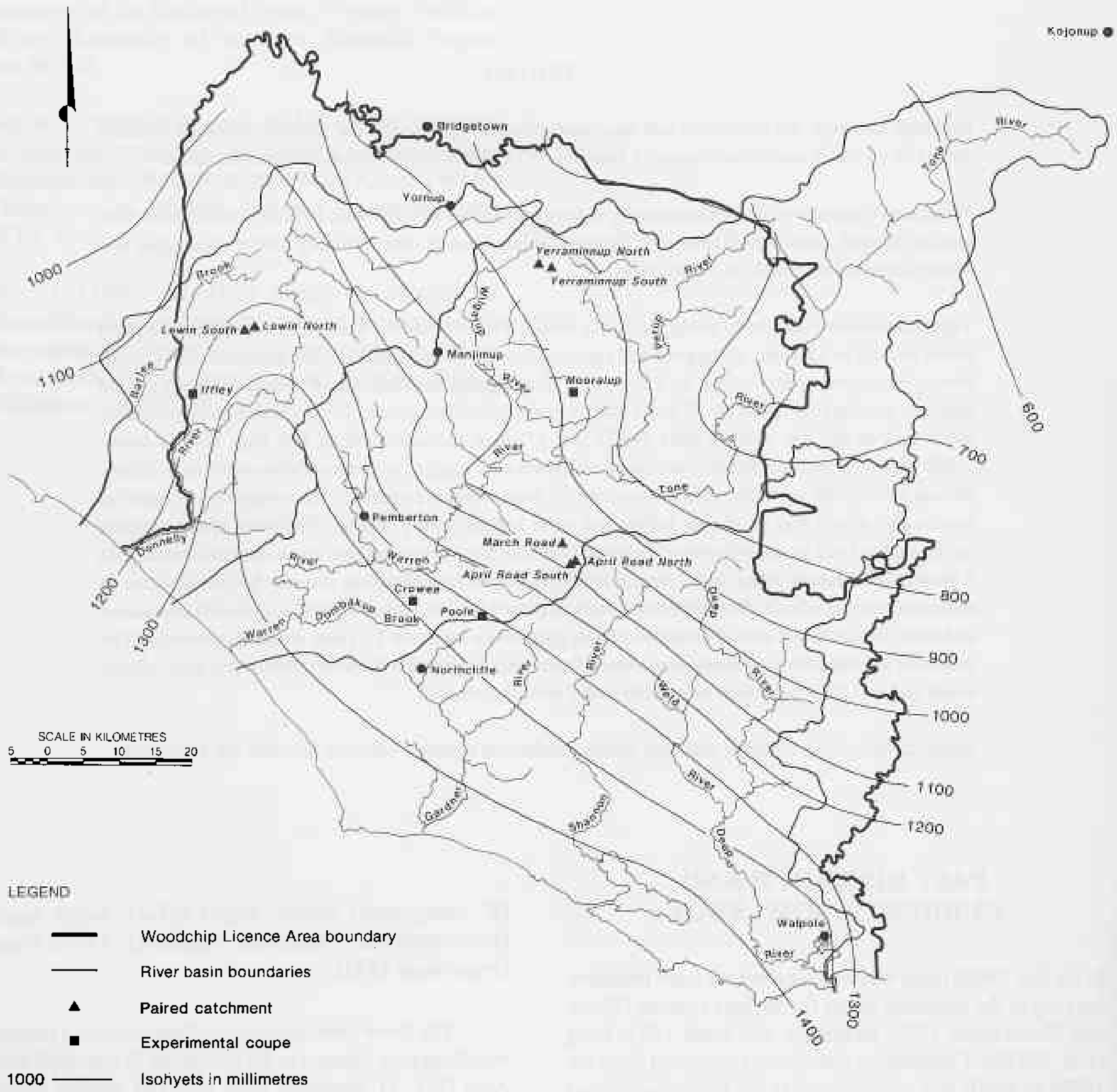

Figure 1
Location of paired catchments (Project 2) and experimental coupes (Project 4)

Research Program

The research program of the Steering Committee For Research on the Woodchip Industry involved four major projects:

PROJECT 1
Areas vulnerable to salinity increase were identified by (a) an extensive borehole drilling program of sampling for soil salt storage from 1974-1976 (Johnston *et al.* 1980), (b) an historical assessment of land clearing and its affect on salinity from records dating back to 1911 (Department of Agriculture 1974), and (c) stream salinity sampling in two major partly cleared catchments in the intermediate rainfall zone (900-1100 mm y^{-1}) during 1977 with the results correlated with land use and other catchment characteristics (Steering Committee 1980).

PROJECT 2
A detailed paired-catchment experiment was established to provide accurate information on changes caused by the proposed logging operations to both surface and groundwater hydrology (Steering Committee 1978, 1980, 1987; Borg *et al.* 1987a; Martin 1987). Seven experimental catchments in three groups covering the range of rainfall, landform, soils and forest types were established (Fig. 1). Measurements of rainfall, stream salinity and sediments, streamflow, groundwater level and groundwater salinity began in 1975 and data were analysed to 1985. Following a pre-treatment calibration, one catchment in each group was left as a control and the others were logged and regenerated in accordance with the current range of forest management practices. In this way, changes in streamflow volumes, salinities and sediment loads caused by the catchment treatment could be identified, independent of their large natural variations. In addition, about 10 to 12 groundwater bores on each catchment were established to measure the response of the groundwater system to the catchment treatment. Logging began in 1982 and most logging and regeneration operations were completed by the winter of 1983. Post-treatment results from three years of monitoring were analysed (Borg *et al.* 1987a; Martin 1987). Measurements of vegetation density were taken during 1986 in these catchments and on other sites with a range of times since regeneration to relate to the changes in catchment hydrology (Stoneman *et al.* 1988; Stoneman *et al.* 1989; Borg and Stoneman 1991).

PROJECT 3
Major rivers in the southern forest were monitored to measure any large-scale changes in water quality caused by logging. Daily sampling for sediment and salinity concentrations was carried out at 12 gauging stations, with varying proportions of forest and agricultural development, from 1975 up to 1986 for most stations. Data have been reported up to 1979. Historical records of stream salinity dating back to 1961 were also analysed (Steering Committee 1980).

PROJECT 4
Four operational coupes, selected as experimental catchments (Fig. 1), were monitored for one year prior to logging in 1977. Monitoring was not as thorough as in the Project 2 catchments and pre-treatment calibration was very limited. Measurements of rainfall, streamflow, stream salinity, groundwater level and groundwater salinity were taken from 1975 to 1985 (Steering Committee 1978, 1980, 1987; Borg *et al.* 1987b, 1988b). The nine years of post-treatment data that were analysed from these experimental coupes have provided valuable information, particularly on the longer term groundwater responses to logging (Borg *et al.* 1987b, 1988b). Measurements of vegetation density were also taken in these catchments as described above for Project 2 (Stoneman *et al.* 1988; Stoneman *et al.* 1989; Borg and Stoneman 1991).

Research Results

PROJECTS 1 and 3
Where salinity increases were reported within the Manjimup district, they were found to be associated with permanent clearing in the intermediate and low rainfall zones (<1100 mm y^{-1}) (Department of Agriculture 1974). This is distinct from timber harvesting operations which are followed by rapid regeneration of the deep-rooted vegetation. It was found that logging associated with the woodchip industry could have a deleterious effect on stream salinity only in areas where sufficiently large quantities of salt are stored in the landscape. Soil salt storage generally increases with decreasing mean annual rainfall (Fig. 2) (Johnston *et al.* 1980). Evidence from these and other studies in forest areas of the Darling Range (Dimmock *et al.* 1974; Stokes *et al.* 1980; Johnston 1981; Tsykin and Slessar 1985), have shown the most hazardous conditions for stream salinity occur in the lateritic soils of the low rainfall zone (<900 mm y^{-1}) where soil solute concentrations are >2000 mg L^{-1} total soluble salts (TSS). A moderate salinity hazard also exists in the intermediate rainfall zone (900-1100 mm y^{-1}).

Experience with Projects 1 and 3 indicates that over extended periods in the intermediate rainfall zone there has been some introduction of salt to rivers from areas of permanent clearing. However, results from these projects suggested that there would be no substantial increases in stream salinity following the logging and regeneration. The results also show that in the high rainfall zone (>1100 mm y^{-1}) woodchipping poses no salinity risks to the region's water resources.

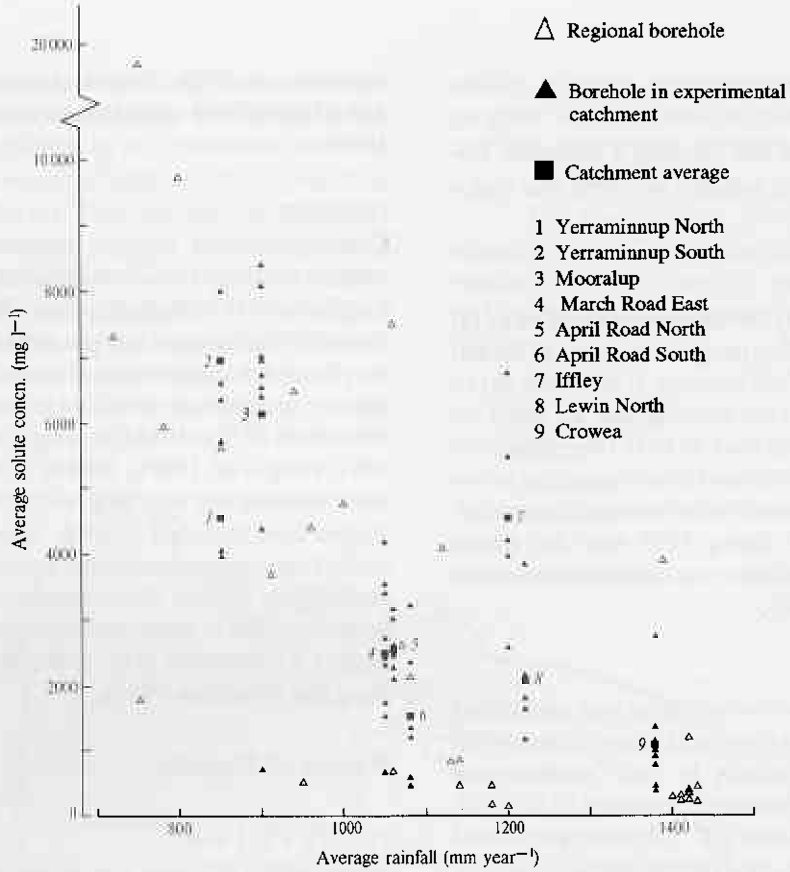

Figure 2
Soil solute concentration in relation to mean annual rainfall (from Johnson *et al.* 1980).

In forested areas in the low rainfall zone groundwater is generally characterized by high salinity (>2000 mg L^{-1} TSS) and great depth below the surface (usually >4 m and often >15 m) (Borg *et al.* 1987a, 1987b; Schofield *et al.* 1989). Except in very dissected landscapes, this saline groundwater needs to rise a great distance before it is able to enter the streams. This would normally take a long time with no forest cover (groundwater rises of 0.8 m y^{-1} were estimated by Loh and Stokes (1980) for a low rainfall zone area following clearing, and groundwater rises of 1.3 m y^{-1} were found following clearing of 54 per cent of a low rainfall zone catchment near Collie (Peck and Williamson 1987)), and much longer with a little forest cover (groundwater rises of 0.4 m y^{-1} followed strip and parkland clearing of 38 per cent of a low rainfall zone catchment near Collie (Peck and Williamson 1987)). On the other hand, in the higher rainfall zones the groundwater is fresher (<2000 mg L^{-1}), more widespread (>50 per cent of catchment areas) and closer to the surface, so it often flows direct to streams under natural forest conditions (Schofield *et al.* 1989).

PROJECTS 2 and 4

Rainfall ~ Rainfall for the study period (1975-1985) was 10 per cent below the long-term mean. The drier conditions are likely to have reduced the size of the hydrologic response to logging and regeneration, but not the general trends (Borg *et al.* 1987a, 1987b, 1988b).

Vegetation cover ~ The vegetation regenerated quickly in all rainfall zones (Fig. 3). In karri stands vegetation cover approached unlogged levels within 5 to 10 years and while actively growing to maturity would achieve higher densities than the original mature forest unless thinned. Jarrah-marri stands responded more slowly, reaching 90 per cent of unlogged cover in about 10 to 15 years (Stoneman *et al.* 1988).

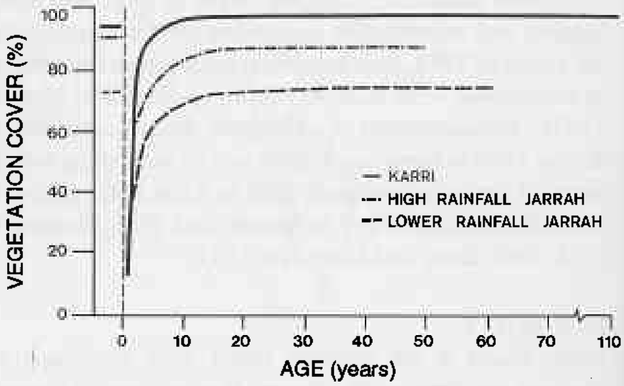

Figure 3
Relationship between vegetation cover and stand age for lower and high rainfall jarrah stands and karri stands (from Stoneman *et al.* 1989).

Groundwater Responses ~ In the Project 4 catchments, permanent groundwater levels (relative to control bores) rose for two to four years after logging and then started to decline (Fig. 4). The groundwater levels were still higher than pre-logging values eight years after logging, but were continuing to decline. Assuming (the then) current rates of decline, it was estimated to take a further five years for the permanent groundwaters to return to the level they would have been without logging i.e. 13 years after regeneration (Borg *et al.* 1987b, 1988b). Three years after regeneration commenced on the treated Project 2 catchments, groundwater levels approached their peak or began to decline on the jarrah-marri catchments but had yet to reach their peak on the karri catchments (Borg *et al.* 1987a).

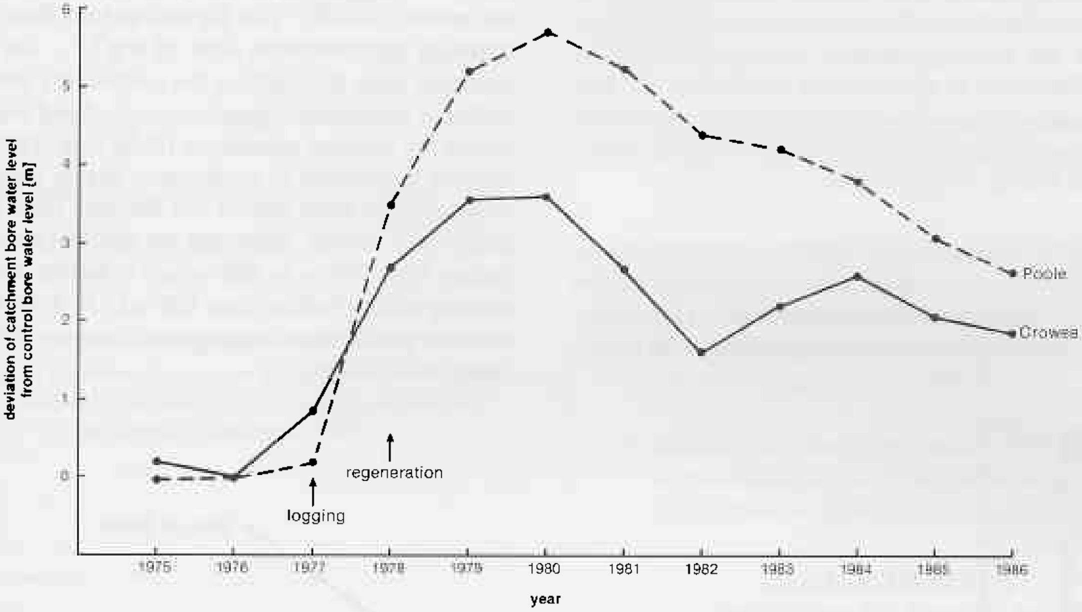

Figure 4
Changes in groundwater level relative to control boreholes following logging in two experimental coupes (from Borg *et al.* 1987b).

Results from both projects showed that groundwater responses to logging were much less in the low rainfall zone than in the intermediate and high rainfall zones (>900 mm y^{-1}) (Borg *et al.* 1987a, 1987b, 1988b). Changes in groundwater level were shown to relate to vegetation cover with the rise in groundwater level ceasing when vegetation cover reached the value for unlogged stands (Fig. 5) (Stoneman *et al.* 1989).

Stream Salinity Responses ~ Small increases in annual flow-weighted stream salinities of between 50 and 150 mg L^{-1} TSS occurred on most treated experimental areas (Fig. 6) (Borg *et al.* 1987a, 1987b, 1988b). However, all annual flow-weighted salinities remained below 500 mg L^{-1} TSS, the limit for high quality drinking water. In the Project 4 catchments, maximum annual stream salinities occurred two years after regeneration commenced, and salinities have since declined (Borg *et al.* 1987b, 1988b). In the Project 2 catchments, annual salinities were highest in 1985, two years after regeneration commenced (Borg *et al.* 1987a). The largest increase in annual flow-weighted salinities (about 150 mg L^{-1} TSS) occurred on a clearfelled catchment in the intermediate rainfall zone which did not have a stream vegetation buffer (Borg *et al.* 1987a). Salinity during periods of low flow on this catchment increased from 700 mg L^{-1} pre-logging to more than 1500 mg L^{-1} post-logging, although these values occurred mainly during the first few weeks of winter flow. Salinities in excess of 1500 mg L^{-1} occurred for over 10 per cent of the time of flow during 1985, but only represented 1 per cent of the flow volume (Borg *et al.* 1987a).

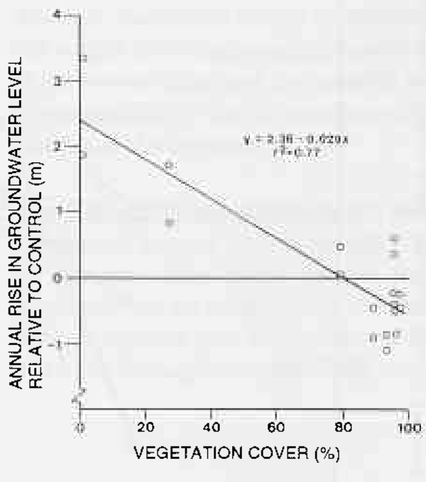

Figure 5
Relationship for karri forest between annual change in groundwater level relative to control boreholes and vegetation cover (from Stoneman *et al.* 1989).

Since the research program began there has been particular interest in the effect of the new logging strategies on water quality in the low rainfall zone where the soil salt storage is high (Environmental Protection Authority 1973). However, experimental results have shown there was no stream salinity increase in this area (Borg *et al.* 1987a, 1987b, 1988b). This is because recharge was small and the depth to groundwater was sufficiently large so that groundwater (the major source of salt) did not contribute to streamflow following logging (Borg *et al.* 1987a, 1987b, 1988b).

In the intermediate and high rainfall zones, groundwater contributed to streamflow before logging. Following logging in these zones, permanent groundwater levels rose and stream salinities increased, indicating an increase in the discharge of salts from groundwater to streams. Similarly, as groundwater levels began to fall following regeneration, stream salinities fell. It is expected that stream salinities will return to near pre-logging values (Borg *et al.* 1987a, 1987b, 1988b).

From a regional water resource perspective, the salinity increases observed are minor. However, the low flow salinities measured at greater than 1500 mg L^{-1}, if they persist for many weeks, could cause problems with small-scale public water supply systems based on low-volume storages. This problem can be overcome by appropriate design of vegetative stream buffers (Steering Committee 1987).

Sediment Concentrations – Stream sediment concentrations before logging were less than 5 mg L^{-1} in all monitored catchments (Steering Committee 1978, 1980, 1987; Borg *et al.* 1987a). Sediment concentrations increased on two of the four paired catchments and remained high for one to two years following logging, before declining to pre-logging levels over the next three years (Fig. 7) (Borg *et al.* 1987a). The catchments where measurable increases in sediment concentrations occurred had no buffer of streamline vegetation retained and were logged through the winter periods. The highest annual flow-weighted sediment concentrations were 38 mg L^{-1}. No sediment increases were detected on the catchments which had a buffer of streamline vegetation retained and were logged during dry summer conditions (Borg *et al.* 1987a). Less detailed monitoring of trials where stream buffer widths were reduced were carried out through 1985 and 1986 (Borg *et al.* 1987a). Reducing the width of existing river buffers from 200 m to 100 m, and reducing the width of existing stream buffers from 100 m to 50 m had no effect on water quality when logging took place over the summer (Borg *et al.* 1987a).

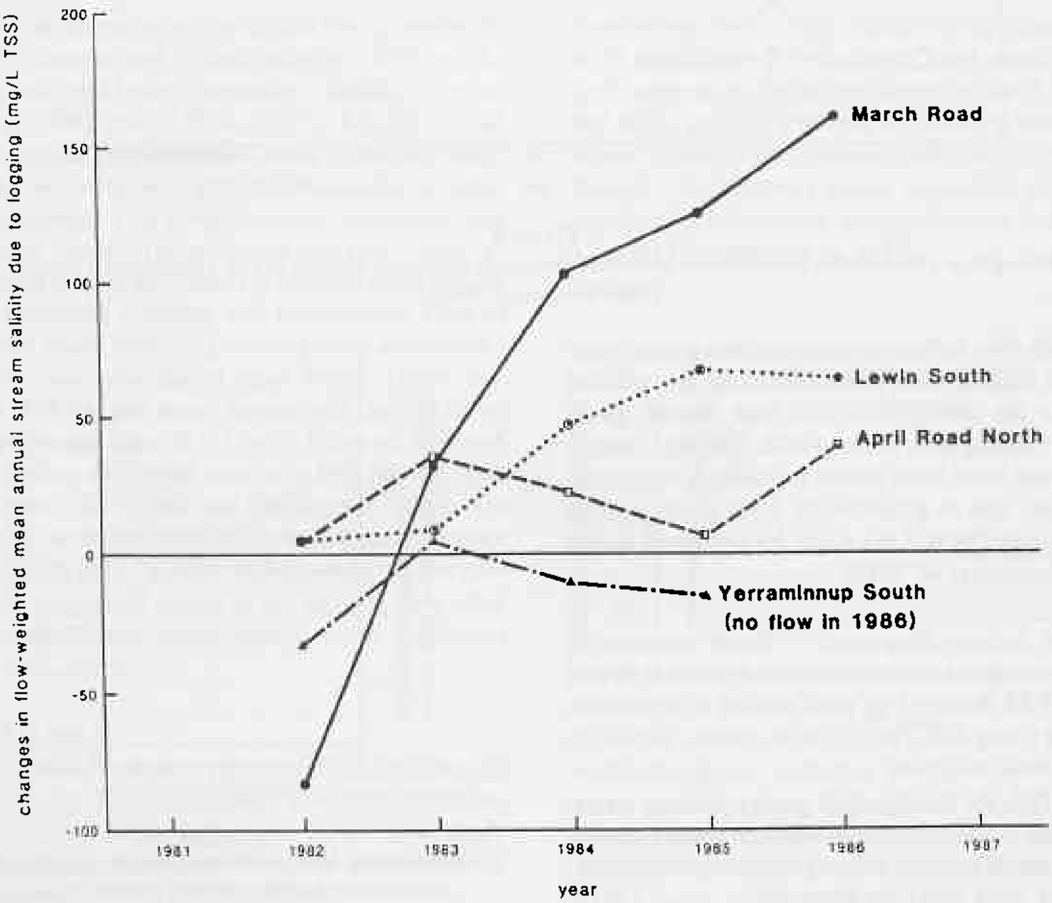

Figure 6

Changes in flow-weighted mean annual stream salinity in the four logged research catchments (from Borg *et al.* 1987a).

In a regional water resources context, the sediment increases were minor, caused in part by the practice of wide dispersal of the logging operations. These stream sediment increases would be of concern to a drinking water supply storage of small volume and short retention time as insufficient time would be available for turbidity levels to reduce in the storage (Steering Committee 1987).

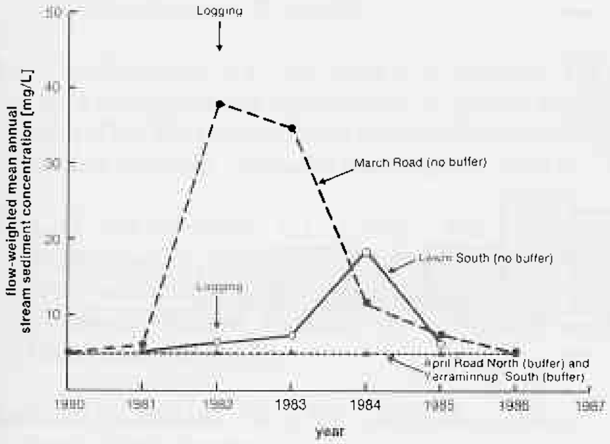

Figure 7
Changes in flow-weighted mean annual stream sediment concentration in the four logged research catchments (from Steering Committee 1987).

Water Yield ~ Streamflow volumes increased at all sites for two to three years after logging and then began to decline (Borg *et al.* 1987a, 1987b, 1988b). The Project 2 catchment results indicated a doubling of streamflow volumes in these early years (Borg *et al.* 1987a). In the high and intermediate rainfall zones, these increases were about 10 per cent of rainfall, whereas in the low rainfall zone the increase was less than 5 per cent of rainfall (Borg *et al.* 1987a, 1987b, 1988b). Results from the Project 4 catchments suggest that streamflows will return to pre-logging levels by about 12 years after logging and regeneration (Fig. 8) (Borg *et al.* 1987b, 1988b). If all stands were subsequently left unthinned (which is not proposed), a significant reduction in water yield could result (Borg and Stoneman 1991) over a period of the stand life.

CURRENT RESEARCH

The research effort has scaled down and emphasis placed on the most critical areas. Project 1 finished in 1981 and all but groundwater monitoring on the Project 4 catchments was discontinued at the end of 1985. The Department of Conservation and Land Management is responsible for monitoring these boreholes. The major stream sediment sampling program (Project 3) was discontinued on all but one stream at the end of 1986. The Water Authority of Western Australia is responsible for monitoring this stream. However, the program has not yet had time to fully quantify the hydrologic effects of timber harvest and regeneration. Only three years post-treatment data were available for the Project 2 catchments. This research, which is the reponsibility of the Water Authority of Western Australia, is continuing to:

1. quantify the longer term water yield and stream solute concentration changes and groundwater responses;
2. evaluate the effectiveness of phased logging and regeneration in minimizing stream sediment and salinity concentrations, and groundwater responses, by logging and regenerating of the stream reserve on April Road North catchment;
3. measure the long-term water yield response of regrowth karri forests at the Sutton Block catchments and determine appropriate thinning regimes.

HIGH PRIORITY ADDITIONAL RESEARCH

Additional work is needed to:

1. develop practicable means of assessing the local risks of salt mobilization and groundwater discharge in the intermediate and low rainfall areas. This is a responsibility of the Department of Conservation and Land Management;
2. develop appropriate stream buffer definitions and subsequent logging and regeneration prescriptions for stream zones based on the more accurate assessment of the local salinity and sediment risks. This should be a joint Department of Conservation and Land Management and Water Authority effort.

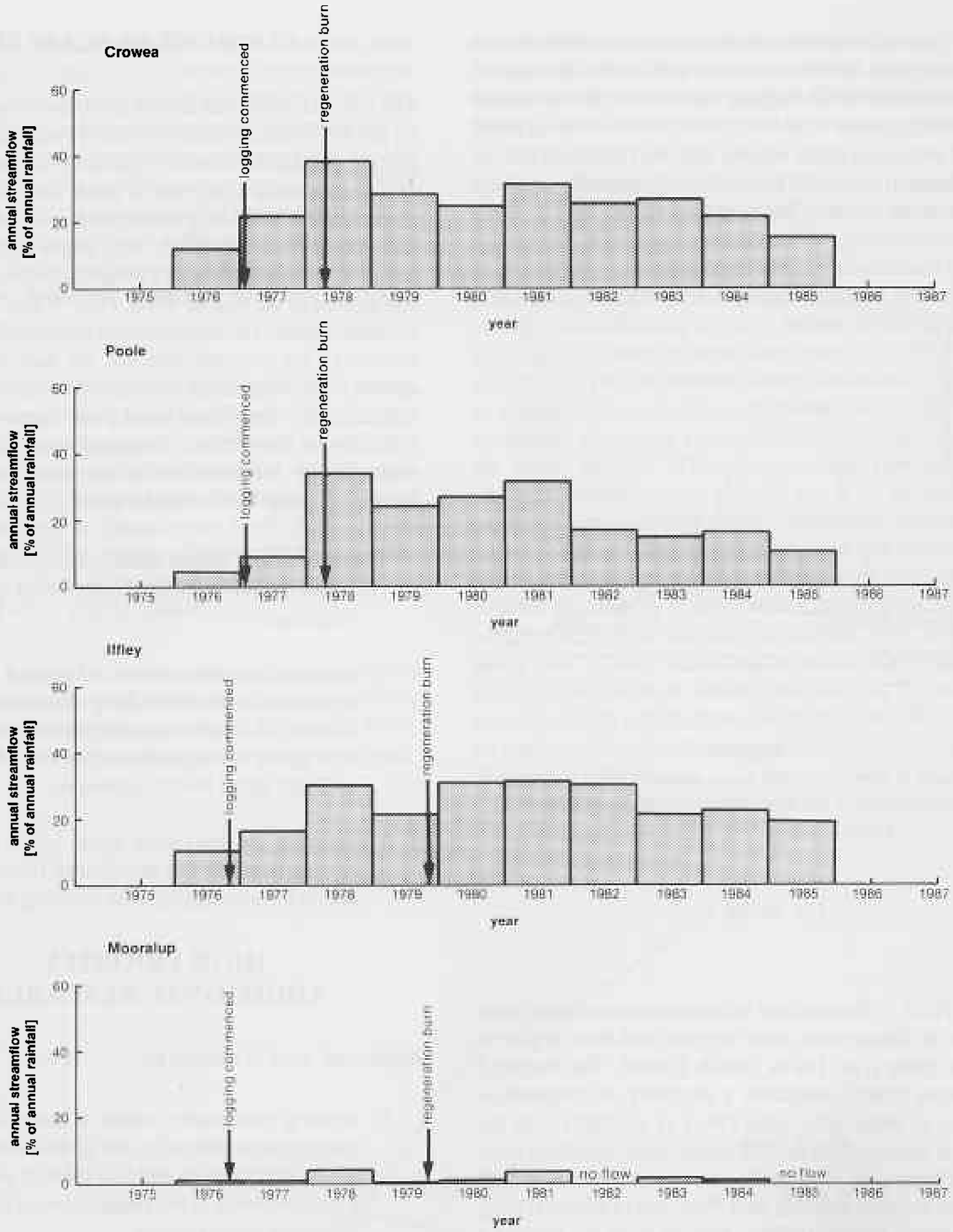

Figure 8
Annual streamflow in the four logged experimental coupes
(from Steering Committee 1987).

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