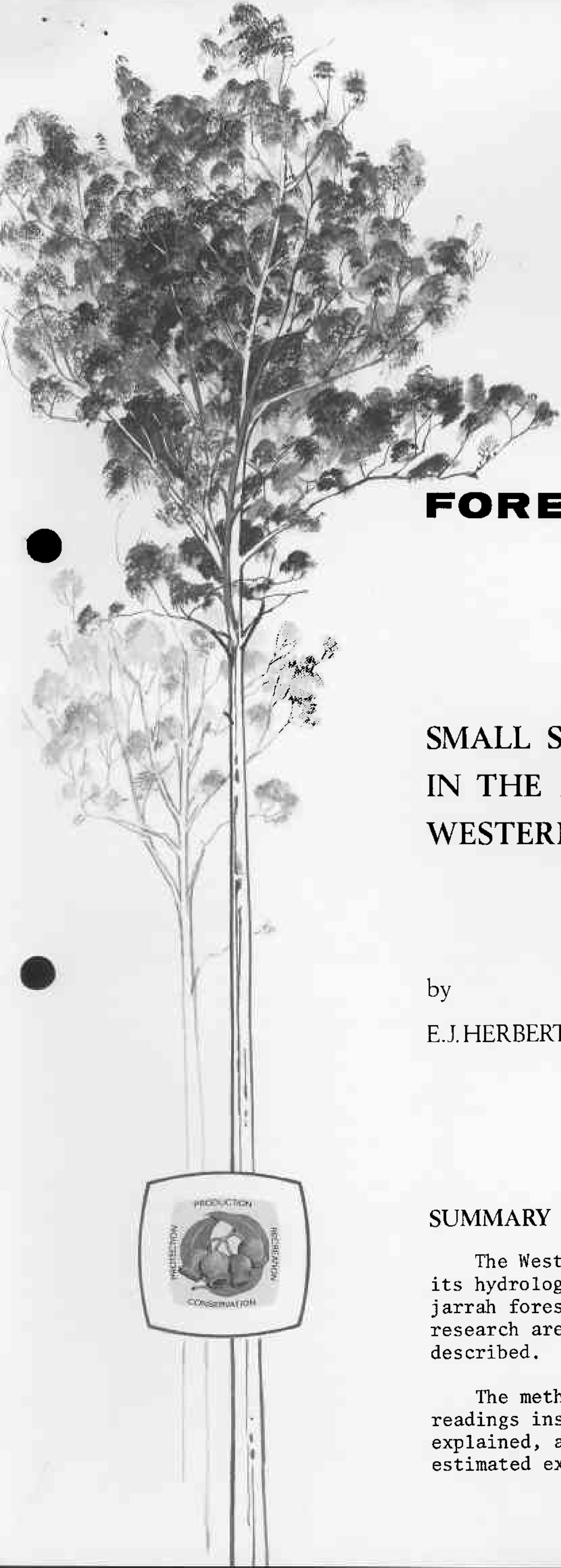

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FORESTS DEPARTMENT
OF WESTERN AUSTRALIA

SMALL STREAMFLOW MEASUREMENTS IN THE NORTHERN JARRAH FOREST, WESTERN AUSTRALIA

by

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SUMMARY

The Western Australian Forests Department started its hydrological research programme in the northern jarrah forest in 1973. The areas and objects of research are outlined, and the type of weir used is described.

The method of flow measurement using staff gauge readings instead of continuous-recorder traces is explained, and the error involved with this method is estimated experimentally.

INTRODUCTION

The Western Australian Forests Department started its hydrological research programme in the northern jarrah forest in 1973. Since then many microcatchments have been monitored for both salt and water yield within the Yarragil and South Dandalup Catchments (Figure 1). The aims of this research are:

(1) to relate water and salt yield to catchment characteristics such as topography, climate, soils and vegetation within the above catchments;

(2) to use the information obtained from (1) in a wider context by extrapolation to characterize the hydrological cycle of the northern jarrah forest. As the catchments studied contain representatives of the variables (forest type, rainfall, geomorphology) which affect water quality and quantity in the northern jarrah forest, such extrapolation is possible.

Because of the large number of microcatchments studied (50) it was not economically possible to construct elaborate weirs with continuous water-level recorders on all streams. Instead, combination V-notch weirs were designed, and their staff gauges were read three times a week. From these readings total streamflows were calculated.

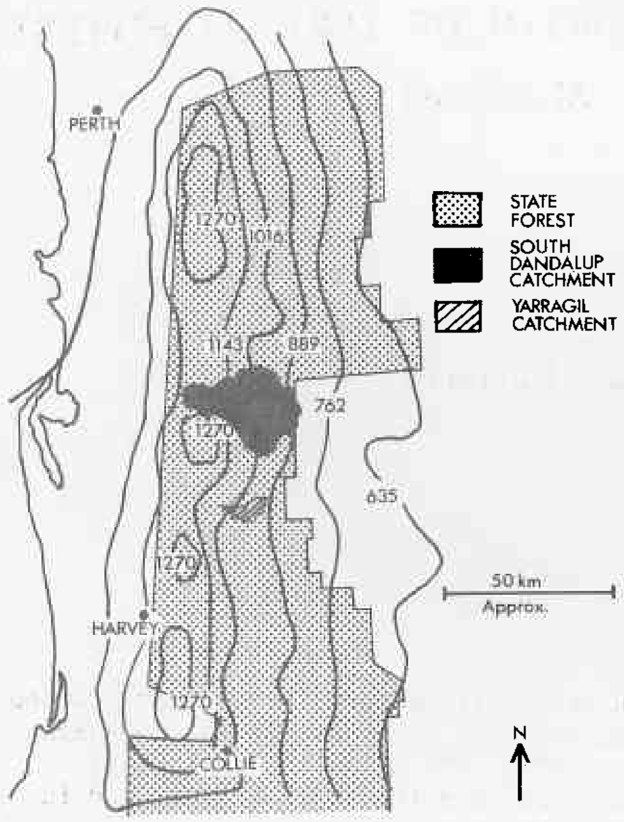

FIGURE 1: The northern jarrah forest showing the location of the South Dandalup and Yarragil Catchments; rainfall is in millimetres

This paper describes the type of weir used, the method of flow measurement, and an experimental estimation of the degree of error involved with the method.

METHOD

Weir design

Weir plate - Each plate was made from 6 mm mild steel and fabricated as a combination 90° V-notch with a rectangular top section (Figure 2). This design was chosen as it adequately measures the range (0.00001 - 0.5 m^3/s) of flows in the study areas; the V-notch accurately measures small flows and the rectangular section caters for the larger, less frequent flows. Plates have also been fabricated from aluminium, and this material will be used in future as it requires less maintenance than mild steel.

Staff gauge - Stage (or head (H) of water above the bottom of the V-notch) was read from a wooden staff gauge graduated in 0.01 m which had its zero level corresponding to the V-notch bottom (Figure 3). To minimize eddying and drawdown, the gauge had a 45° bevelled edge on its upstream side and its long axis parallel to the direction of flow. To avoid the effect of surface drawdown at the weir crest, the gauge was positioned upstream from the weir at a distance equal to four times the maximum expected stage (Stevens, 1970) (Figure 4).

Installation - A backhoe was used to dig a trench which usually extended 20-30 cm below the clay zone across the creek to ensure minimal seepage beneath the weir. The trench was long enough to allow concrete wings to be set well into the creek banks; these wings may be extended by earth embankments in broad valley sites.

Because the flow formula requires that the approach velocity of water to the weir is not more than 0.3 m/s, a stilling pond was created by widening the upstream area immediately above the weir. The dimensions of this pond depend upon the volume and velocity of the expected flow; ponds which measured 3-4 m across by 5 m upstream were

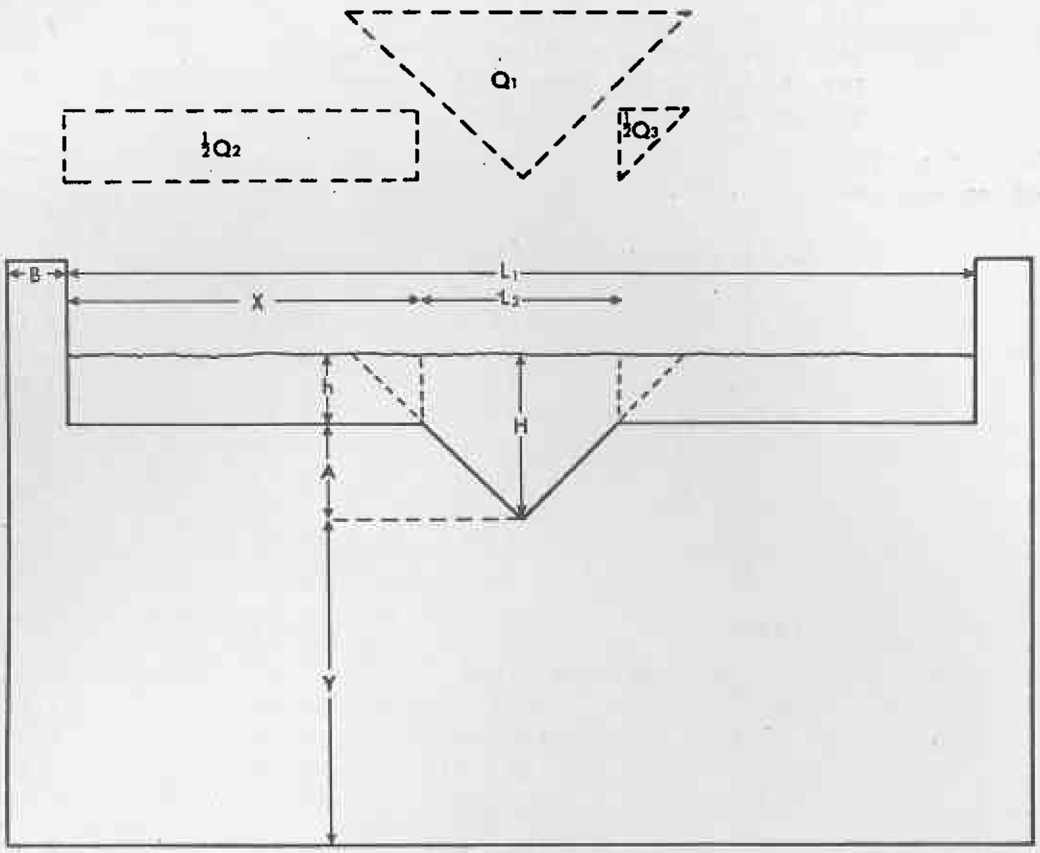

FIGURE 2: Combination 90° V-notch weir plate (upstream side)

A = depth of V-notch (variable)
B = width of end contractions
H = total head above V-notch base
h = head above top of V-notch
L_1 = width between end contractions
L_2 = width of top of V-notch

$Q_1 = 1.34H^{2.48}$
$Q_2 = 1.82 \times (L-0.2h)h^{1.5}$ where $L = L_1 - L_2$
Q_3 = the area of overlap between Q_1 and Q_2

Stevens' specifications:
Where H = maximum expected head
Y = greater than twice H
and X = greater than twice H

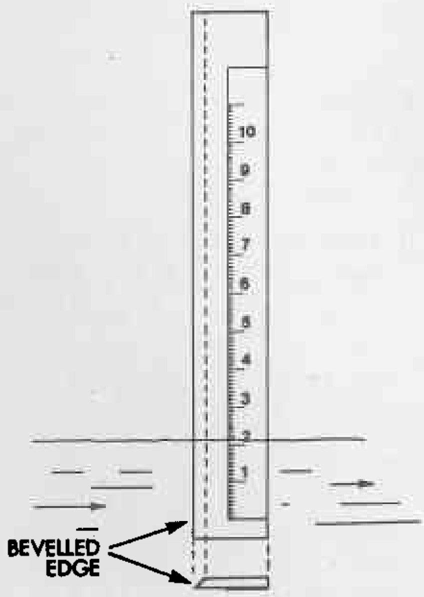

FIGURE 3: Staff gauge illustrating bevelled edge and direction of flow

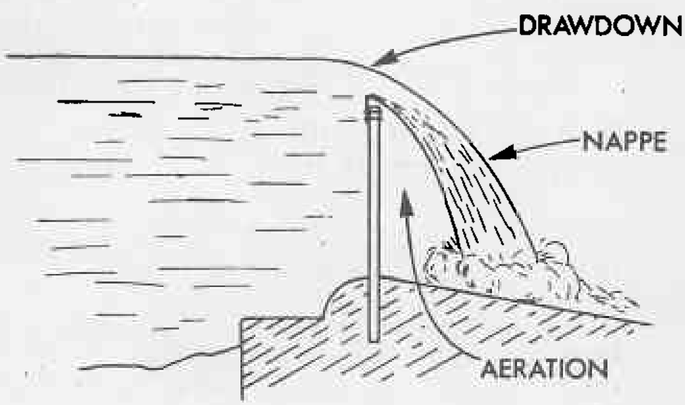

FIGURE 4: Section through a weir plate showing a sharp crest, surface drawdown and aeration under the nappe (adapted from Stevens, 1970)

TABLE 1

Comparison of flows calculated from:
(A) three stage readings a week;
(B) continuous recording hydrographs;
for Dwellingerup Brook (East Branch), Seldom Seen Creek and Yarragil Brook

Year	No. of months of record used	A	B*	Difference B-A	% difference $\frac{B-A}{B} \times \frac{100}{1}$
		Dwellingerup Brook, East Branch			
1960	7	124.21	126.56	-2.34	-1.8
1961	7	152.58	168.86	-16.28	-9.6
1962	7	138.77	147.89	-9.13	-6.2
1963	7	315.40	318.61	-3.21	-1.0
1964	7	406.06	434.92	-28.86	-6.6
1966	7	165.29	170.84	-5.55	-3.2
1967	7	233.13	233.00	0.12	0.0
1968	7	272.72	284.44	-11.72	-4.1
1969	7	143.95	143.70	0.25	0.2
1970	7	220.05	226.71	-6.66	-2.9
TOTAL		2172.16	2255.54	-83.38	-3.7
		Seldom Seen Creek			
1967	4	1727.24	1958.77	-231.52	-11.8
1968	3	1770.04	1756.60	13.44	0.7
1969	6	1220.16	1232.99	-12.83	-1.0
1970	7	2554.54	2574.15	-19.61	-0.7
TOTAL		7271.98	7522.50	-250.52	-3.3
		Yarragil Brook			
1966	5	3582.65	4202.47	-619.82	-14.7
1967	6	7440.97	7038.48	402.48	5.7
1968	7	6223.77	6497.23	-273.46	-4.2
1969	7	1580.95	1585.64	-4.69	-0.3
1970	6	4793.43	4887.79	-94.36	-1.9
TOTAL		23621.77	24211.61	-589.95	-2.4

* For each year only those months with a complete record were used to calculate (B) - generally from April till October

TABLE 2

Comparison of flows calculated from:
(A) simulating use of high-water gauges with three stage readings a week;
(B) continuous recording hydrographs;
for Seldom Seen Creek and Yarragil Brook

Year	No. of months of record used	A	B*	Difference B-A	% difference $\frac{B-A}{B} \times \frac{100}{1}$
		Seldom Seen Creek			
1970	7	3236.28	2574.15	662.13	25.7
		Yarragil Brook			
1966	5	4504.67	4202.47	302.20	7.2
1967	6	8789.66	7038.48	1751.17	24.9
1968	7	7161.58	6497.23	664.35	10.2
1969	7	2008.10	1585.64	422.47	26.6
1970	6	5487.88	4887.79	600.09	12.3
TOTAL		27951.89	24211.61	3740.28	15.4

* For each year only those months with a complete record were used to calculate (B) - generally from April till October

adequate for most weir sites.

Formwork was constructed to contain the concrete foundation and wings. The weir plate was set at right angles to the direction of flow, and according to Stevens' (1970) specifications: the distance between the bottom of the V-notch and the upstream creek bed (Figure 2, Y) was 2-2.5 times the maximum expected head (Figure 2, H) to prevent a velocity head developing as the water approached the plate; the distance between the edge of the V-notch and the nearest end contraction (Figure 2, X) was 2 or more times the maximum expected head.

For the formula used to calculate flow to apply, the crest of the weir over which the water passes should be cut with a sharp upstream corner so that the water springs clear. Otherwise, clinging of a portion of the nappe will occur, especially at low stages (Figure 4). Sharp cresting was accomplished by bolting and sealing a 1 mm thick galvanised steel facing (cut to the particular weir's dimensions) to the upstream side of the weir plate. Such sharp crests were effective, cheap, and easy to replace.

Submergence of the nappe resulting in a reduction in accuracy may occur if the distance between the V-notch bottom and the downstream bed is too small; the water must spring clear from the crest, thus aerating (Figure 4). To allow for this it may be necessary to lift the plate to a height which involves construction of excessively large containing walls. These walls could cause unnecessary ponding upstream which attenuates the peak and may unnaturally raise the water-table level behind the cut-off wall in periods of normally small or nil surface flow. Thus the site may have to be abandoned or a lower cut-off wall built in conjunction with a channel constructed downstream (Bowyer, P.W.D. Water Resources Section, pers. comm.).

A concrete spillway was constructed on the downstream creek bed immediately behind the weir to prevent the effluent water from eroding the otherwise bare earth surface. Construction time per weir averaged 12 man-days.

Rating curves - Where it was physically impossible to construct a weir, or where the expense of a weir was not justified but some flow data were required, flow was measured with a current meter over a range of stage readings, and a stage-flow or rating curve was produced. From this rating curve a regression equation for conversion of stage readings to flows was calculated. The above procedure may be carried out on established weirs to:

(1) check the readings obtained from stage-flow relationships by measuring flow immediately above or below the weir;
(2) establish a stage-flow relationship for those weirs which do not meet the specifications outlined in the section on weir design.

Current-meter measurement procedure is described at length by Buchanan and Somers (1969) and the Western Australian Public Works Department (P.W.D.) (1968).

Costs

Average costs per weir have been calculated using values as at 1 April 1976:

(1) construction costs including materials, machinery and labour = \$560;
(2) running costs per year including maintenance, data collection and analysis = \$266.

The running costs for Yarragil and South Dandalup Catchments have been costed against weir inspection only. However, many other parameters were monitored during the periods of inspection, and if the costs of these were calculated the above running costs would be reduced.

Calculations

Formulae relating stage to discharge are given by the United States Department of the Interior (1971) (parameters are defined in Figure 2 caption):

$$Q = 1.34 \times H^{2.48}$$

where Q = discharge (m^3/s) for a 90^o V-notch weir,

and

$$Q = 1.82\ (L - 0.2h)h^{1.5}$$

for a rectangular weir with end contractions.

The method of calculating discharge using the above formulae has been described by Bowyer (P.W.D. Water Resources Section, pers. comm.) and involves three calculations.

(1) Calculation of discharge (Q_1) through the V-notch. The head (H) above the V-notch is used specifically for the V-notch formula for any given stage

reading. Thus the V-notch extrapolates to the water surface for stage readings higher than the depth of the V-notch section (A in Figure 2).

(2) Calculations of discharge through the rectangular sections ($\frac{1}{2}Q_2 + \frac{1}{2}Q_2$). This discharge is calculated using $L = L_1 - L_2$ in the rectangular-weir formula above.

(3) Calculation of overlaps ($\frac{1}{2}Q_3 + \frac{1}{2}Q_3$). As the V-notch extrapolates to the water surface, some overlap with the rectangular sections results. The combined overlaps form a 90° triangle which has a discharge calculated by using the formula for a 90° V-notch weir.

The total discharge (Q) for stages higher than the depth of the V-notch section can now be calculated:

$$Q = Q_1 + Q_2 - Q_3.$$

For stages equal to or less than the height of the V-notch section, only the V-notch formula (1) is required, and therefore:

$$Q = Q_1$$

Errors

Stevens (1970) considers that under normal field conditions the correlation between stage and flow for weirs probably has a basic error of at least 3-5%. Buchanan and Somers (1969) consider that flows from a V-notch weir can be measured to within 3% accuracy.

Three stage readings a week - The weirs installed in the Yarragil and South Dandalup Catchments were inspected and their staff gauges read three times a week (Mondays, Wednesdays and Fridays). A study was undertaken to determine the additional error introduced by calculating annual flows from three stage readings a week rather than from continuous flow recordings. Three streams representing the range of catchments measured by the Forests Department were used: Dwellingerup Brook, East Branch (0.72 km^2); Seldom Seen Creek (6.89 km^2); Yarragil Brook (72.52 km^2). For each of these streams, varying months of P.W.D.'s continuous streamflow records were selected from years with minimal missing data (Table 1), and instantaneous flows were taken from the hydrographs at 1200 h on every 2nd, 4th and 6th day of each week to simulate the method used. Assuming that the change in flow from one reading to the next was uniform, monthly and yearly flows were calculated to form a simulated hydrograph, and then compared with the P.W.D.'s calculation of flows based on continuous recordings (Table 1).

Three stage readings a week with peak flows between readings - Low-cost high-water gauges were installed in the stilling ponds of 28 weirs in the Yarragil Catchment and 5 weirs in the South Dandalup Catchment. For a detailed description of these gauges see Mason (1975). The object of these installations was to record peak flow between the periods of inspection. Thus, it was assumed the extra high-water-level readings would, when combined with the staff gauge readings obtained thrice weekly, give a more accurate estimate of total streamflow. To test this assumption a similar comparative test to that previously described was undertaken.

Peak flows between staff gauge readings were determined from maximum instantaneous daily flows for Seldom Seen Creek (1970) and for Yarragil Brook (1966-1970) (P.W.D.,1972). Because the time of peak flow was not known, and in most cases it was impossible to weight the high-water reading towards either staff gauge reading, peak flow was recorded on the hydrograph mid-way between the times of the two staff gauge readings. Flows calculated from this simulated hydrograph were then compared with P.W.D.'s calculations from continuous recordings; results are shown in Table 2.

RESULTS

The totals from Table 1 show that flows calculated by the three-readings-a-week method underestimate flows calculated from continuous recordings by 2-4%.

The totals from Table 2 show that when peak flows were used to supplement the three-readings-a-week method, gross overestimation of total streamflow resulted. In the smaller (6.89 km^2) Seldom Seen Catchment, simulated flow exceeded actual flow by 25.7%. Similarly, in the larger (72.52 km^2) Yarragil Catchment, simulated flow exceeded actual flow by 15.4%.

The greatest monthly variations between the simulated flows and actual flows occurred during June, July and August. These variations, often as much as 10%, tended to cancel each other out as one month would be -10% and another +10%, whilst their total flows were approximately equal. Variations for September, October and November were small (0-5%) owing to the long and uniform recession phase exhibited by the streams studied.

DISCUSSION AND CONCLUSIONS

The small percentage differences in Table 1 indicate that by taking three staff gauge readings a week, converting them to flows, and adding these weekly flows over the total period of flow, streamflow can be conservatively and reasonably accurately estimated.

The estimate reflects the uniform yield characteristics of the catchments studied. Elliott (1972), in a study of yield characteristics of catchments in the south-west of Western Australia, concluded that high-yielding catchments show a smaller variability in monthly flow and a greater proportional contribution to streamflow from groundwater than catchments with lower yields. The contribution from groundwater produces the prolonged and uniform recession phase observed during September, October and November when variations between the actual and simulated flows were smallest.

Similar observations for south-western catchments have been made by Clark (1970). This worker attributed the characteristically wider and lower peaks on the hydrographs to the slower rate of flow caused by the temporary storage of water throughout the catchment.

These yield characteristics also explain the overestimation of flow when simulated high-water gauge readings were used: the peak flows plotted on the hydrographs were not balanced by minimum flows, and hence the method, which assumes linear changes in flow from one reading to the next, does not simulate real conditions. Readings taken every Monday, Wednesday and Friday without the inclusion of peak flows simulate the rises and falls in the continuous hydrographs more accurately.

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