# HYDROLOGICAL EFFECTS OF A CHANGE IN LAND USE FROM RAIN FOREST TO TEA PLANTATION IN KENYA

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## SUMMARY

Two adjacent catchments of 700 ha and 540 ha situated at 2,200 m in a montane rain forest area 0.3° south of the equator in western Kenya, were selected for this study. Geological evidence suggested that these catchments were watertight and subsequent evidence from the results has tended to confirm this conclusion. The catchments were instrumented to measure total rainfall input, streamflow and soil moisture changes. After an intercalibration period 50% of the area of the larger catchment was cleared and planted to tea over four years. By the end of the period for which results are presented the tea was approaching its mature level of ground cover.

A simple water balance model yielded yearly values of evapotranspiration, *Et,* close to 80% of Penman open water evaporation, *Eo,* for both catchments. Whilst *Et/Eo* remained essentially constant for the forested catchment, the figure for the treated catchment declined by some 10% during the transition period, then rose again to the 80% level as the tea approached maturity. Surface runoff doubled from an initial 1% of the incident rainfall during the transition period before dropping again to the 1% level as the tea established.

The conclusion drawn is that the land use change resulted in a small increase in total streamflow yield during the transition period, but at 5 years after planting the difference was insignificant. The study is being continued until the tea plantation reaches maturity.

## RÉSUMÉ

### *EFFETS HYDROLOGIQUES D'UN CHANGEMENT DE L'UTILISATION DES TERRES: TRANSFORMATION D'UNE FORET EQUATORIAL ET HUMIDE EN PLANTATION DE THE AU KENYA.*

Deux bassins de réception adjacents de 700 et 540 hectares situés à une altitude de 2.200 m dans une région montagneuse de forêt equatoriale et humide à 0,3° au sud de l'équateur dans l'ouest du Kenya ont été choisies pour cette étude. D'après les données géologiques, ces deux bassins étaient imperméables; les observations ultérieures ont été dans le sens de cette conclusion. Dans les bassins de réception, des appareils ont été installés pour mesurer les changements de l'apport total de précipitation, de l'écoulement et de l'humidité du sol. Après une période d'interétalonnage, 50% de la superficie du bassin de réception le plus grand ont été défrichés et on y a planté des arbres à thé pendant quatre ans. A la fin de la période pour laquelle on présente des résultats, les arbres à thé approchaient de leur période de maturité quant à la couverture du sol.

Un modèle simple de bilan hyrique a fourni des valeurs annuelles de l'évapotranspiration ($E_t$) voisines de 80% de l'évaporation à partir d'une surface d'eau libre de Penman, $E_o$, pour les deux bassins de réception. Alors que $E_t/E_o$ est resté *grosso modo* constant en ce qui concerne le bassin de réception boisé, le chiffre obtenu pour le bassin traité a diminué de quelque 10% au cours de la période de transition, puis est remonté à 80% lorsque l'arbre à thé a approché de sa maturité. Le ruissellement a doublé par rapport à son pourcentage initial de 1% des précipitations tombées pendant la période de transition avant de revenir au niveau de 1% lorsque l'arbre à thé a pris possession du terrain.

La conclusion est que le changement d'utilisation des terres a entraîné une faible augmentation du débit total au cours de la période de transition, mais que cinq ans après la plantation, la différence était négligeable. L'étude se poursuit jusqu'à ce que la plantation de thé atteigne sa maturité.

## INTRODUCTION

n 1957 a catchment study of the hydrological effects of a change in land use from montane rain forest to tea estates was initiated in Kenya. This was a joint venture by he Kenya Forest Department, the Water Development Department, the Kenya Tea Company and the East African Agriculture and Forestry Research Organization, with urther assistance being provided by the Tea Research Institute of East Africa. The tudy was designed to obtain detailed information on the effects of this land use hange on the water yield from the area both in terms of total yield and seasonal distribution. The establishment of the experiment was described in detail by Pereira *et l.* (1962b). In this paper the methods used and some of the results emerging are ummarised.

## METHODS

ince meaningful results were required within a reasonable time the classical approach f deriving rainfall/streamflow correlations, changing the land use and repeating the rocess was not considered for this experiment. Instead it was decided to use a water alance approach to estimate and compare the evapotranspiration rates from adjacent treated and control catchments before, during and after the land use change and also o measure and compare the surface runoff. Measurement of the meteorological arameters necessary to compute potential evaporation, $Eo$, using the Penman (1948) method was also included in the programme on the basis that comparison of the vapotranspiration estimates, $Et$, with $Eo$ would provide a useful check on their alidity and also a possible basis for projecting the results obtained to other similar reas.

The model used to estimate $Et$ was the general water balance expression

$$Et = R - Q - \Delta S - \Delta G - L$$

where, over a specified period,

$R$ is the total precipitation on the catchment,
$Q$ is the total streamflow from the catchment,
$\Delta S$ is the increase in water stored within the root range of the vegetation,
$\Delta G$ is the increase in water stored below the root range,
$L$ is the net loss of groundwater from the catchment, other than by streamflow.

Of the terms on the right-hand side of this expression, $R$ and $Q$ can be measured with reasonable accuracy. Since $S$ and $G$ fluctuate about mean values, $\Delta S$ and $\Delta G$ can be ignored if the balance is considered over a sufficiently long period. For suitably hosen shorter periods an estimate of $\Delta S$ may be obtained by soil sampling and $\Delta G$ an be estimated from groundwater measurements or from streamflow levels using an ntegration of the baseflow recession curve. The fourth term, $L$, is extremely difficult o measure directly. However, if any confidence is to be placed in the $Et$ values obtained, some estimate of its magnitude is necessary. In the present case it has been ssumed from the geological evidence, and the fact that the streamflow structures are built at suitable sites on exposed rock, that $L$ is negligible. Indirect checks have been applied to the data to estimate the accuracy of this assumption. These will be discussed later in the paper.

Two approaches were adopted in considering the second parameter liable to be affected by the land-use change. Surface runoff or stormflow figures from individual torms have been separated from baseflow. The total stormflow expressed as a percentage of the rainfall provides a basis for comparing the response in different periods. A more detailed study was based on the model

$$q = F(i)(r - S)$$

where $q$ is the stormflow resulting from an individual storm
F ($i$) is a function of the rainfall intensity
$r$ is the storm rainfall
$S$ is a surface storage factor subject to an upper limit $Sm$.

Some results from the application of this method to the Kericho catchments were reported by Dagg and Blackie (1965). In the present paper results from the former method only are presented.

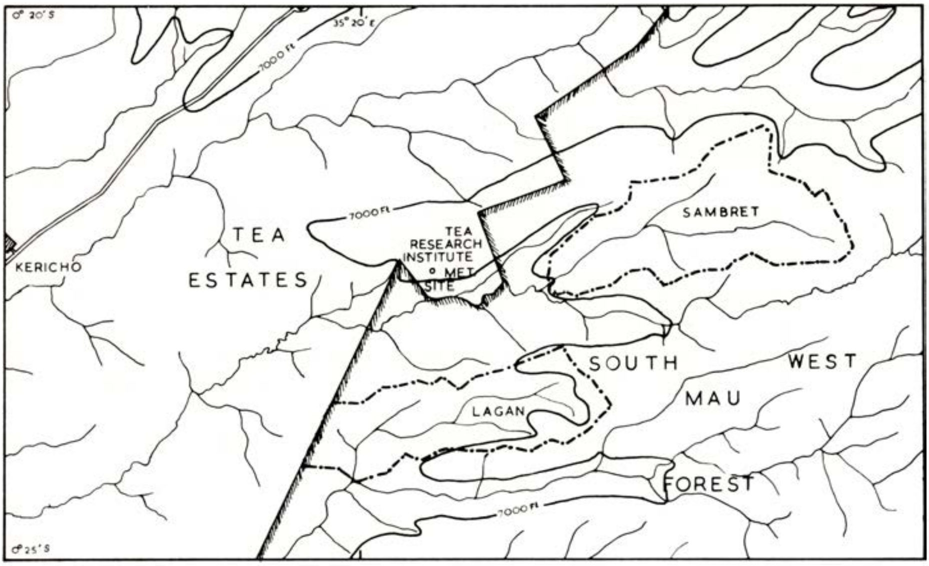

*Figure 1. Relative positions of the control (Lagan) and experimental (Sambret) catchments and the meteorological site.*

## DESCRIPTION OF CATCHMENTS

The catchments are situated in the South-West Mau Forest Reserve in Western Kenya within the Lake Victoria Catchment close to Kericho township, the major centre of tea production in Kenya. This belt of forest, lying between 2,000 m and 2,800 m altitude within 0.5° of the equator, consists of a dense cover of evergreen broad-leaved species giving way to continuous bamboo cover at the higher levels. Rainfall in the range 1,500 to 2,500 mm feeds a close network of perennial streams flowing from the forest westwards through the tea belt and across the densely populated, relatively dry plains to Lake Victoria. From the meteorological data summarised in Table 1 it can be seen that the area experiences low windspeeds and only minor seasonal fluctuations in temperature and humidity. The rainfall distribution is such that restrictions on growth and transpiration can be expected only in the January-February period in the average year.

The catchments chosen are two parallel valleys at a mean altitude of 2,200 m, giving rise to permanent streams (Fig. 1). The control catchment, Lagan, 544 ha in area with an average slope of 4% (Fig. 2) is entirely under forest. The treated

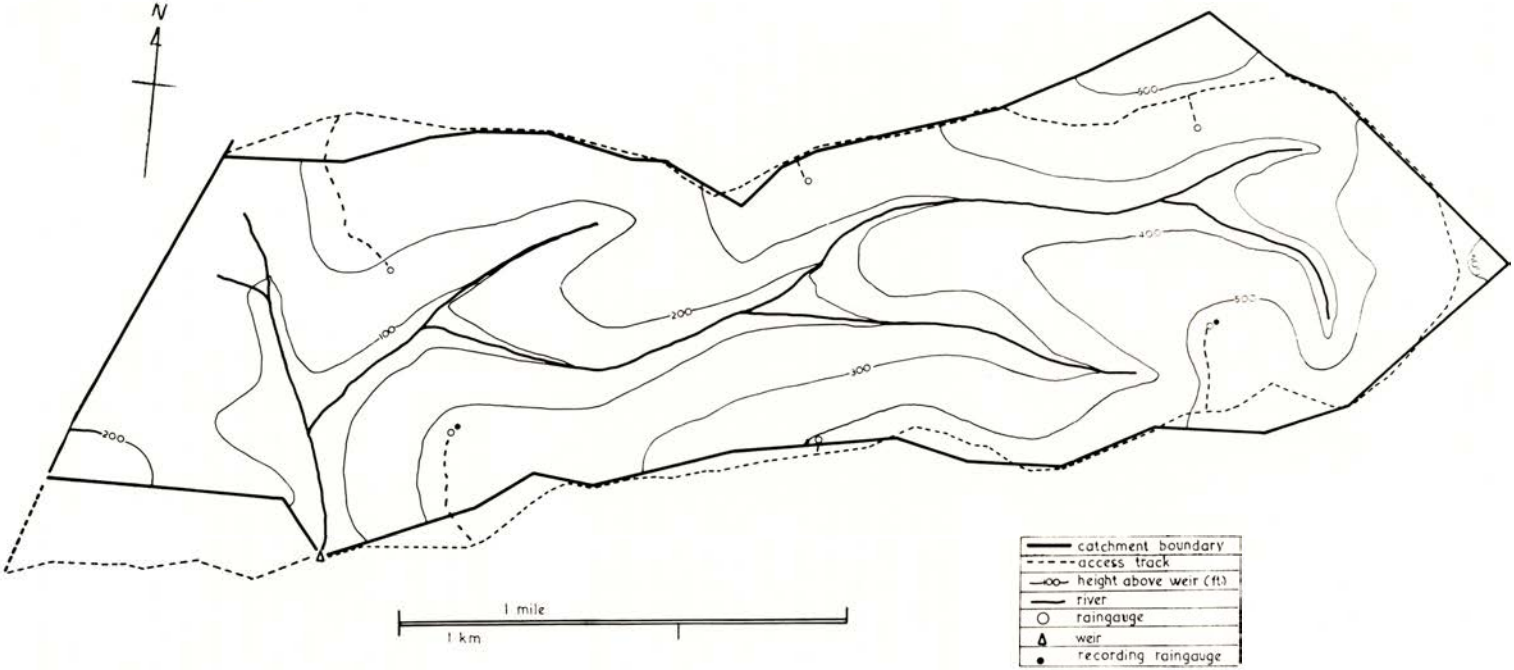

FIGURE 2. *Lagan forested catchment.*

TABLE 1. Summary of meteorological observations at the Tea Research Institute, Kericho (lat. 0°22′S, long. 35°21′E, alt. 2,137 m) for the period 1958-1968.

| *Month* | *Mean monthly means of daily values* | | | | | | | | *Mean monthly totals* | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Max. temp. (°C)* | *Min. temp. (°C)* | *Mean temp. (°C)* | *Dewpoint (°C)* | *Sat. def. (mm Hg)* | *Windspeed at 2 m (km/h)* | *Radiation (langleys per day)* | *Sunshine (hours)* | *Rainfall (mm)* | *Penman E (mm)* |
| Jan | 23.8 | 9.3 | 16.5 | 9.5 | 5.28 | 6.0 | 566 | 8.3 | 68.0 | 172.7 |
| Feb | 23.8 | 9.2 | 16.5 | 10.0 | 4.88 | 5.7 | 560 | 7.9 | 90.7 | 156.2 |
| Mar | 23.6 | 9.6 | 16.6 | 11.0 | 4.39 | 5.5 | 546 | 7.4 | 180.8 | 166.8 |
| Apr | 22.1 | 10.3 | 16.2 | 12.6 | 2.96 | 4.6 | 436 | 5.6 | 300.5 | 127.1 |
| May | 21.7 | 9.9 | 15.8 | 12.7 | 2.53 | 4.7 | 448 | 6.2 | 278.4 | 129.2 |
| Jun | 21.1 | 9.1 | 15.1 | 11.6 | 2.65 | 5.4 | 460 | 6.7 | 202.3 | 126.0 |
| Jul | 20.2 | 9.4 | 14.8 | 11.3 | 2.62 | 5.4 | 417 | 5.7 | 194.3 | 119.7 |
| Aug | 20.4 | 9.3 | 14.8 | 11.4 | 2.66 | 5.8 | 421 | 5.6 | 209.4 | 123.4 |
| Sep | 21.3 | 8.7 | 15.0 | 11.3 | 2.91 | 5.9 | 455 | 6.1 | 187.5 | 129.8 |
| Oct | 21.6 | 9.3 | 15.5 | 11.5 | 3.11 | 5.5 | 437 | 5.8 | 178.5 | 131.8 |
| Nov | 21.6 | 10.0 | 15.8 | 11.6 | 3.24 | 5.3 | 433 | 5.6 | 168.5 | 127.9 |
| Dec | 22.5 | 9.6 | 16.0 | 10.6 | 4.05 | 5.7 | 500 | 7.3 | 108.0 | 150.4 |
| *Total:* | | | | | | | | | 2166.9 | 1661.0 |
| *Mean :* | 22.0 | 9.5 | 15.7 | 11.2 | 3.44 | 5.4 | 473 | 6.5 | | |

catchment, Sambret (Fig. 3), of 702 ha and an average slope of 4.5%, was initially under forest with some 190 ha of mixed bamboo/forest in its upper reaches.

The underlying rock structure in both valleys consists of a deep layer of phonolite described as being exceptionally free from fissures. The deep, porous, heavily leached, stone-free soils weathered from this lava show remarkable uniformity in physical structure over the area and to a depth of over 6 m. Profile details from typical sites in each catchment are given in Table 2. Detailed topographical surveys of both catchments resulted in survey plots with form lines at 10 ft vertical intervals. The surface boundaries were determined from frequent cross sections of the well defined ridges. A detailed check in 1968 yielded the quoted values of the horizontal areas. These are 2.4% and 1.8% higher than the original estimates for Lagan and Sambret. The geology and topography of the area suggest that there should be no major differences between surface and sub-surface catchment boundaries.

## MEASUREMENTS

The methods adopted required that accurate measurements of the total rainfall input, and streamflow be obtained from each catchment. Estimates of soil moisture and groundwater changes were also required as were meteorological data to compute potential evaporation.

The raingauge network on the control catchment, Lagan, comprises six raingauges distributed as shown in Fig. 2. Two of these are tilting-siphon type recording gauges using 25 mm daily charts with a time scale of 11.4 mm per hour, from which intensities are also derived. Daily read check gauges are set beside them. These gauges together with a third standard 5-inch daily gauge on the south side of the catchment are situated in clearings which give a maximum shading angle of 45°. Under the low windspeed conditions encountered in the Kenya highlands this has been shown to be adequate. The three gauges on the northern side of the catchment are mounted on tree platforms at mean canopy level. The catch from these is brought to a daily read storage container at ground level by lengths of PVC cold-water piping. Elsewhere in Kenya, a comparison of this type of gauge with a standard gauge at ground level in an adjacent cleared area showed that the catches were comparable within 1% (Pereira *et al.*, 1962a).

TABLE 2a. Soil profile values of bulk density (BD), field capacity (FC) and wilting point (WP) for equivalent sites on Sambret and Lagan.

| *Depth (cm)* | *Sambret Lower Site* | | | *Lagan Lower Site* | | |
|---|---|---|---|---|---|---|
| | *BD* | *FC (mm)* | *WP (mm)* | *BD* | *FC (mm)* | *WP (mm)* |
| 0-15.2 | 0.68 | 63 | 35 | 0.67 | 68 | 39 |
| 30.5 | 0.82 | 136 | 79 | 0.69 | 131 | 67 |
| 61 | 0.81 | 134 | 79 | 0.78 | 133 | 77 |
| 91 | 0.78 | 128 | 77 | 0.81 | 139 | 84 |
| 122 | 0.81 | 131 | 77 | 0.84 | 145 | 85 |
| 152 | 0.85 | 125 | 77 | 0.87 | 152 | 91 |
| 183 | 0.89 | 129 | 84 | 0.85 | 137 | 88 |
| 213 | 0.92 | 137 | 89 | 0.92 | 138 | 89 |
| 243 | 0.91 | 139 | 83 | 0.93 | 156 | 99 |
| 274 | 0.86 | 131 | 83 | 0.91 | 163 | 96 |
| 305 | 0.90 | 129 | 85 | 0.95 | 160 | 97 |
| *Totals and Means* | 0.84 | 1,382 | 853 | 0.84 | 1,522 | 912 |

TABLE 2b. Mean bulk densities and 3.2 m profile totals of field capacity (1/3 atmosphere) and wilting point (15 atm.) for the soil moisture sampling sites on Sambret and Lagan.

| *Sampling site* | | *Mean bulk density* | *Total field capacity (mm)* | *Total wilting point (mm)* |
|---|---|---|---|---|
| Sambret | Upper | 0.87 | 1,387 | 861 |
| | Middle | 0.80 | 1,473 | 851 |
| | Lower | 0.84 | 1,382 | 853 |
| Lagan | Upper | 0.79 | 1,462 | 898 |
| | Middle | 0.86 | 1,500 | 936 |
| | Lower | 0.84 | 1,522 | 912 |

The original network on the treated catchment, Sambret, consisted of three recording raingauges with adjacent check gauges situated in the upper, middle and lower sectors of the catchment (Fig. 3), supplemented by six 10-day storage gauges set in clearings round the catchment boundary. After some initial clearing had been completed a further network of 18 standard daily read gauges, mounted on posts so that they ultimately sampled rainfall at 30 cm above the canopy level of the tea, was installed. This network, designed to cross-check the data from the basic network, was redistributed in 1965 after the final establishment of the tea estate.

All streamflow measuring structures were designed, installed and had their ratings checked by the Water Development Department. The two main structures are compound sharp-crested and broad-crested weirs whilst that on the forested sub-catchment within Sambret is a compound weir with V-notch, sharp-crested and broad-crested sections. The structures are firmly embedded on rock at sites carefully chosen to minimise the possibility of seepage losses. The ratings provided by W.D.D. are considered to be accurate within 2% over the normal baseflow range and to within

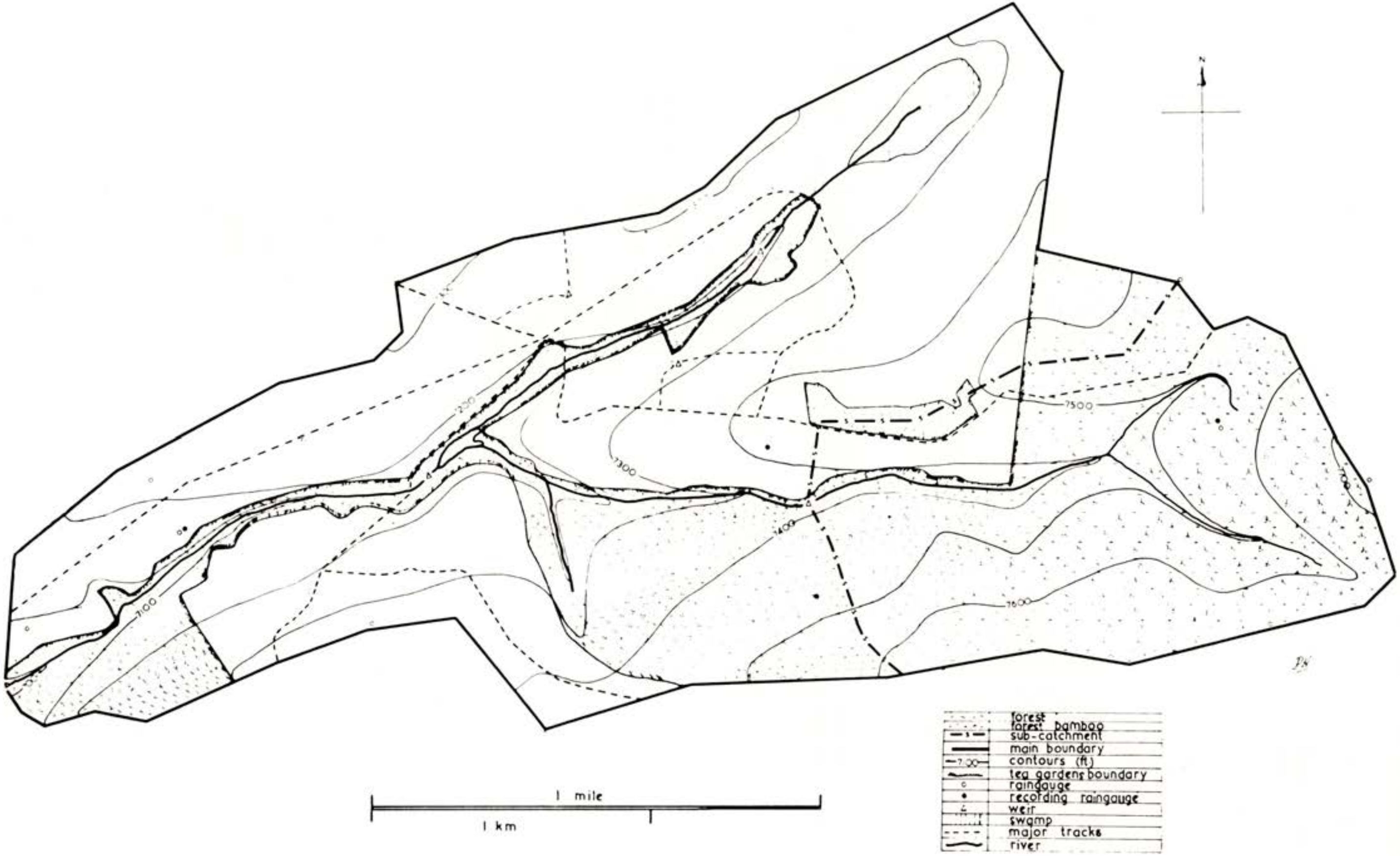

FIGURE 3. *Sambret experimental catchment showing the cleared areas and the sub-catchment.*

5% on the higher peaks (D.T. Plinston, pers. comm.). Continuous water-level records are obtained from Lea Rotary Recorders using weekly charts. Daily staff readings provide a running check on the recorders and also a basis for estimating flow in any periods when they might be out of action. Using templates, hourly values of baseflow and total flow are read from the charts in units of equivalent depth over the catchment. The accuracy of these hourly values is not high. Despite regular attention the residual backlash in the recorder gears can result in water-level errors of the order of 3 mm. The check readings from the staff are also of this order of accuracy. On Lagan this would represent an error varying from ± 10% to ± 1% over the normal flow range. Coupled with the inevitable random errors in reading from a scale of 1.6 mm per hour and a reduction rate of 3:1, individual hourly values are probably not reliable to better than 20%. Since these errors are essentially random, however, it is considered that the long-term total flow has an accuracy approaching that of the structures.

The remarkable uniformity of the soils and vegetation offered the possibility of obtaining reasonable estimates of soil moisture changes within the catchments for a small number of sampling sites. In each catchment three sites representative of the upper, middle and lower areas were chosen. At each site undisturbed core profiles were taken at 30 cm intervals to 3 m and field capacity (1/3 atm.) and wilting point (15 atm.) determinations carried out. Bulk density values were used to convert subsequent gravimetric moisture contents to volumetric profile totals for replicated profiles from each site, taken at monthly intervals. Stratified means of the deficits were then computed and $\Delta S$ obtained from the differences. The maximum depth to which it was practicable to work was 3 m (10 ft). Root studies by Kerfoot (1962) had shown that whereas the root systems of the forest trees, bamboo and tea penetrate beyond 6 m in these soils, the bulk of the roots are in the top 3 m. Evidence of moisture extraction at the 3 m level has been obtained in two dry seasons only under the forest and in one under the tea. Though the absolute accuracy of the mean deficit obtained in this way is open to question, the agreement in trend and hence in the differences, $\Delta S$, should be acceptable. On Lagan the standard error of the mean deficit from the 3 sites rarely exceeded 30 mm.

Using data from the relatively short dry periods when an appreciable moisture deficit existed in the root range, composite baseflow recession curves were constructed (Fig. 4). Integration of flow with time between different flow levels then gave an estimate of the change in groundwater storage, $\Delta G$, between such flow levels.

A meteorological site was established at the nearby Tea Research Institute (Fig. 1) and instrumented to give the temperature, humidity, windrun, sunshine hours and total shortwave radiation necessary to compute Penman $E_o$. Whilst the distance between this site and the catchments will result in day-to-day differences in the $E_o$ figures, its similarity in altitude and in rainfall should not result in any large differences in the long-term cumulative values.

## EXPERIMENTAL PROGRAMME

Instrumentation of the catchments was completed in 1957. After an 18-month calibration period, clearing of the first 120 ha started in late 1959 and this was planted in April 1960. The clearing was completed in 1963 and the last planting done in 1964. Sembret catchment then comprised 128 ha of forest, 190 ha of mixed forest and bamboo, an 8 ha impeded drainage area, and a cleared area of 376 ha distributed as shown in Fig. 3. Of the cleared area 332 ha had been planted to tea, the remainder being accounted for by a 13 ha housing and administrative area and the access road and storm drainage network.

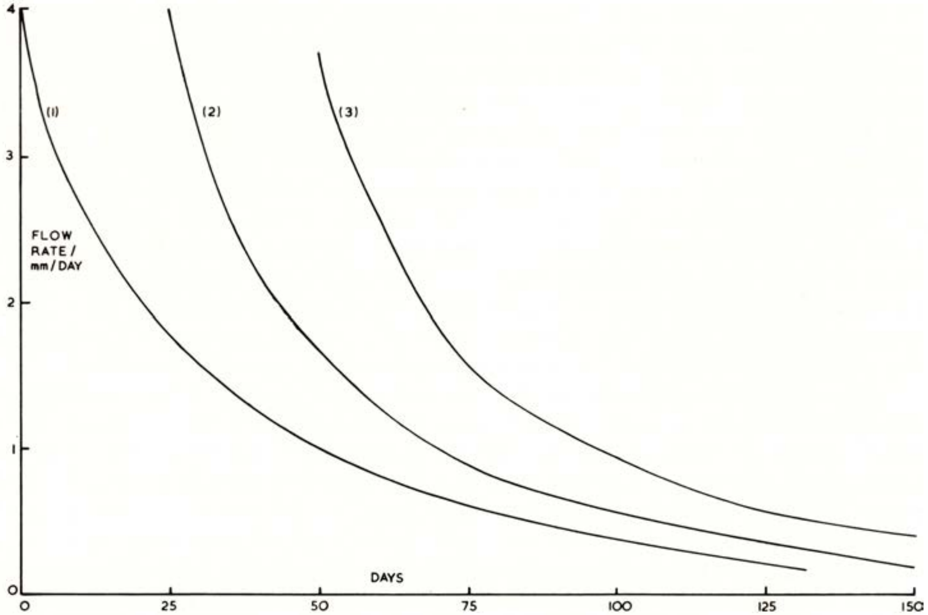

FIGURE 4. *Composite baseflow recession curves for Lagan (1), Sambret (2) and Sambret sub-catchment (3).*

Since it was not possible to convert the entire catchment to tea estate, a sub-catchment taking in most of the area under mixed forest and bamboo was instrumented in 1960 to provide a measurement of the water use from the uncleared area.

By the end of 1968 the earliest tea was in full production and ground cover in the last planting was approaching its final level. Evapotranspiration rates and stormflow levels could therefore be considered to be close to their stable level under the new pattern of land use.

## RESULTS

In 1969 the raw data from these catchments for the period 1958 to 1968 were transferred to computer tape. This exercise formed part of a co-operative programme of research between EAAFRO and the British Institute of Hydrology. After the application of a quality control programme the data were assembled on master tapes in the form of daily catchment rainfall, daily streamflow and daily Penman *Eo*. Monthly values of these parameters are presented in Tables 3, 4 and 5.

Catchment rainfall was computed using the Thiessen weighting method. Apart from a few months when gauges were unserviceable, the six-gauge network was used throughout on Lagan. A consistent difference of +6% between corresponding southern and northern gauges was noted. The absence of any obvious north-south gradient on neighbouring Sambret suggested that the difference may be due to the differing exposures of the canopy level northern and ground level southern gauges.

For Sambret, the rainfall for the period 1958 to September 1960 was obtained from the three recording gauges only. From October 1960 onwards the 21 gauge network was used. Comparison of the results from the 3 gauges and the 21 gauges for the period 1960 to 1965, when the 18 daily gauges were redistributed, and from 1965

TABLE 3. Lagan catchment rainfall (R) and streamflow (Q) in mm.

| | | | | | | | | | | | | | *11-year means* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *1958* | *1959* | *1960* | *1961* | *1962* | *1963* | *1964* | *1965* | *1966* | *1967* | *1968* | *R&Q* | *Raindays* |
| Jan | *R* | 52.3 | 77.5 | 111.5 | 10.6 | 135.7 | 181.1 | 13.8 | 33.1 | 26.2 | 7.7 | 18.4 | 60.7 | 10 |
| | *Q* | 9.6 | 13.1 | 23.0 | 26.1 | 133.7 | 37.3 | 45.7 | 23.2 | 21.7 | 17.9 | 60.7 | 37.4 | |
| Feb | *R* | 171.7 | 103.0 | 105.6 | 26.5 | 38.7 | 115.5 | 81.8 | 8.2 | 105.1 | 30.6 | 242.1 | 93.5 | 12 |
| | *Q* | 10.7 | 8.8 | 14.4 | 12.8 | 52.5 | 28.2 | 24.3 | 12.6 | 20.2 | 12.0 | 36.2 | 21.1 | |
| Mar | *R* | 244.1 | 190.3 | 233.4 | 127.3 | 166.7 | 127.1 | 176.8 | 143.3 | 150.5 | 172.8 | 174.6 | 173.4 | 17 |
| | *Q* | 12.6 | 11.4 | 17.7 | 10.7 | 34.2 | 25.5 | 20.6 | 13.7 | 22.7 | 13.3 | 35.5 | 19.8 | |
| Apr | *R* | 192.4 | 205.3 | 302.6 | 217.4 | 330.0 | 347.4 | 417.5 | 250.4 | 275.8 | 251.2 | 333.0 | 283.9 | 24 |
| | *Q* | 9.4 | 13.5 | 47.0 | 12.0 | 37.7 | 44.5 | 68.1 | 17.7 | 46.4 | 18.4 | 77.4 | 35.6 | |
| May | *R* | 251.1 | 222.3 | 364.0 | 263.5 | 360.7 | 233.0 | 227.0 | 134.9 | 132.3 | 352.0 | 209.1 | 250.0 | 25 |
| | *Q* | 31.8 | 29.2 | 132.4 | 20.0 | 183.5 | 179.4 | 87.3 | 20.0 | 84.2 | 47.7 | 162.3 | 88.9 | |
| Jun | *R* | 161.3 | 115.5 | 175.9 | 164.0 | 206.9 | 118.6 | 197.0 | 76.5 | 192.8 | 213.3 | 263.1 | 171.4 | 24 |
| | *Q* | 29.1 | 22.8 | 145.4 | 14.7 | 131.4 | 78.8 | 97.5 | 13.3 | 72.1 | 64.2 | 130.0 | 72.7 | |
| Jul | *R* | 123.5 | 101.2 | 161.5 | 161.7 | 284.9 | 174.4 | 199.5 | 115.8 | 132.4 | 157.4 | 226.1 | 167.1 | 22 |
| | *Q* | 35.4 | 18.2 | 88.9 | 18.9 | 164.3 | 44.0 | 127.2 | 13.8 | 59.0 | 87.1 | 133.7 | 71.9 | |
| Aug | *R* | 192.9 | 136.6 | 208.5 | 293.9 | 197.4 | 211.3 | 76.1 | 128.0 | 147.6 | 238.5 | 296.5 | 193.4 | 24 |
| | *Q* | 32.3 | 18.2 | 57.4 | 62.6 | 103.6 | 47.0 | 108.5 | 18.4 | 50.9 | 82.3 | 160.5 | 67.4 | |
| Sep | *R* | 142.6 | 198.3 | 305.6 | 288.4 | 274.4 | 67.7 | 211.0 | 132.7 | 155.8 | 208.5 | 217.5 | 200.2 | 23 |
| | *Q* | 41.6 | 29.4 | 128.7 | 76.6 | 107.8 | 60.4 | 80.2 | 19.9 | 137.1 | 86.9 | 139.4 | 82.5 | |
| Oct | *R* | 166.2 | 204.1 | 162.0 | 217.2 | 199.1 | 117.5 | 182.7 | 140.7 | 90.2 | 171.0 | 165.9 | 165.1 | 24 |
| | *Q* | 46.7 | 36.6 | 120.7 | 130.2 | 98.1 | 37.2 | 129.9 | 22.2 | 73.1 | 84.3 | 85.6 | 78.6 | |
| Nov | *R* | 67.9 | 167.8 | 212.2 | 482.8 | 53.8 | 212.5 | 76.0 | 177.1 | 129.9 | 198.9 | 176.7 | 177.8 | 20 |
| | *Q* | 28.7 | 50.1 | 95.5 | 220.0 | 58.4 | 29.1 | 73.8 | 57.4 | 41.3 | 80.5 | 66.5 | 72.8 | |
| Dec | *R* | 113.6 | 50.5 | 40.1 | 269.8 | 177.2 | 205.4 | 74.7 | 93.3 | 2.4 | 113.1 | 103.1 | 113.0 | 14 |
| | *Q* | 19.2 | 33.3 | 57.5 | 245.3 | 38.7 | 83.5 | 37.3 | 36.2 | 27.6 | 126.7 | 86.5 | 72.0 | |
| *Totals* | *R* | 1879.6 | 1772.4 | 2382.9 | 2523.1 | 2425.5 | 2111.5 | 1933.9 | 1434.0 | 1541.0 | 2115.0 | 2426.1 | 2049.5 | |
| | *Q* | 307.1 | 284.6 | 928.6 | 849.9 | 1143.9 | 694.9 | 900.4 | 268.4 | 656.3 | 721.3 | 1174.3 | 720.9 | |
| *Total raindays* | | 230 | 225 | 261 | 257 | 254 | 243 | 274 | 213 | 185 | 242 | 255 | | 239 |

TABLE 4. Sambret catchment rainfall (R) and streamflow (Q) in mm.

| | | | | | | | | | | | | | *11-year means* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *1958* | *1959* | *1960* | *1961* | *1962* | *1963* | *1964* | *1965* | *1966* | *1967* | *1968* | *R&Q* | *Raindays* |
| Jan | *R* | 46.3 | 60.6 | 109.0 | 2.9 | 148.9 | 159.0 | 9.2 | 65.6 | 30.5 | 11.8 | 10.0 | 58.3 | 10 |
| | *Q* | 7.8 | 9.5 | 20.2 | 20.4 | 91.8 | 43.7 | 39.2 | 17.6 | 22.2 | 14.7 | 38.3 | 29.6 | |
| Feb | *R* | 182.0 | 98.0 | 102.3 | 41.4 | 27.2 | 111.3 | 49.7 | 1.2 | 172.4 | 24.1 | 247.2 | 96.1 | 11 |
| | *Q* | 9.2 | 7.4 | 14.2 | 12.8 | 51.6 | 37.9 | 19.6 | 10.1 | 15.9 | 9.2 | 23.1 | 19.2 | |
| Mar | *R* | 156.9 | 217.5 | 227.1 | 126.4 | 119.5 | 140.7 | 182.1 | 135.4 | 199.1 | 158.4 | 126.4 | 162.7 | 17 |
| | *Q* | 7.9 | 11.4 | 19.8 | 12.1 | 32.5 | 32.7 | 18.1 | 10.7 | 17.5 | 9.6 | 24.4 | 17.9 | |
| Apr | *R* | 135.7 | 268.3 | 299.2 | 166.0 | 453.6 | 373.7 | 388.8 | 282.9 | 312.9 | 213.7 | 308.7 | 291.2 | 23 |
| | *Q* | 5.7 | 24.5 | 73.3 | 12.8 | 76.9 | 73.6 | 71.9 | 14.7 | 51.9 | 10.9 | 62.9 | 43.5 | |
| May | *R* | 284.2 | 238.0 | 285.1 | 293.6 | 413.7 | 320.8 | 210.1 | 129.5 | 161.5 | 423.8 | 216.4 | 270.6 | 25 |
| | *Q* | 15.0 | 55.1 | 130.2 | 61.4 | 293.9 | 298.0 | 130.7 | 28.6 | 127.2 | 80.9 | 135.0 | 123.3 | |
| Jun | *R* | 194.5 | 120.0 | 112.9 | 185.8 | 210.1 | 146.7 | 225.2 | 100.2 | 170.2 | 289.2 | 271.0 | 184.2 | 23 |
| | *Q* | 26.1 | 44.0 | 115.2 | 42.3 | 169.5 | 93.7 | 107.0 | 22.6 | 61.9 | 160.6 | 160.5 | 91.2 | |
| Jul | *R* | 116.4 | 182.7 | 183.2 | 106.7 | 314.1 | 213.2 | 318.5 | 122.4 | 172.2 | 218.1 | 237.9 | 198.7 | 25 |
| | *Q* | 29.6 | 31.0 | 84.3 | 50.5 | 177.3 | 72.1 | 156.5 | 17.2 | 56.8 | 178.2 | 118.1 | 88.3 | |
| Aug | *R* | 241.0 | 188.5 | 211.7 | 292.1 | 191.1 | 239.5 | 185.2 | 175.4 | 169.5 | 196.4 | 213.5 | 209.4 | 26 |
| | *Q* | 30.2 | 62.1 | 53.9 | 102.3 | 143.8 | 80.3 | 137.8 | 18.7 | 55.6 | 90.2 | 144.4 | 83.6 | |
| Sep | *R* | 78.0 | 176.3 | 440.8 | 304.7 | 206.7 | 54.0 | 224.1 | 62.1 | 215.5 | 214.8 | 120.0 | 190.6 | 23 |
| | *Q* | 54.3 | 66.9 | 216.0 | 142.5 | 86.8 | 86.9 | 123.3 | 19.4 | 111.6 | 95.3 | 85.6 | 99.0 | |
| Oct | *R* | 148.7 | 136.8 | 126.6 | 203.2 | 227.6 | 74.6 | 182.8 | 212.0 | 128.9 | 127.4 | 138.9 | 155.2 | 24 |
| | *Q* | 29.6 | 51.1 | 137.2 | 144.2 | 108.1 | 35.7 | 130.7 | 20.8 | 54.7 | 78.8 | 41.8 | 75.6 | |
| Nov | *R* | 63.3 | 166.3 | 162.9 | 424.1 | 47.3 | 198.5 | 53.6 | 167.1 | 117.5 | 220.9 | 111.5 | 157.5 | 20 |
| | *Q* | 16.7 | 50.6 | 72.2 | 184.7 | 76.5 | 24.8 | 54.8 | 34.5 | 58.7 | 58.7 | 38.4 | 60.5 | |
| Dec | *R* | 138.1 | 22.8 | 46.8 | 204.9 | 163.3 | 184.1 | 85.0 | 115.2 | 11.9 | 115.4 | 68.8 | 105.1 | 15 |
| | *Q* | 12.8 | 29.2 | 41.1 | 193.9 | 39.2 | 71.2 | 27.6 | 41,4 | 25.6 | 116.7 | 32.5 | 57.4 | |
| *Totals* | *R* | 1785.1 | 1875.8 | 2307.6 | 2351.8 | 2523.1 | 2216.1 | 2114.3 | 1569.0 | 1862.1 | 2214.0 | 2070.3 | 2079.6 | |
| | *Q* | 244.9 | 442.8 | 977.6 | 979.9 | 1347.9 | 950.6 | 1017.2 | 275.2 | 635.4 | 903.8 | 905.0 | 789.1 | |
| *Total raindays* | | 235 | 232 | 253 | 258 | 245 | 238 | 244 | 226 | 242 | 247 | 259 | | 243 |

TABLE 5. Kericho catchment Penman Eo in mm.

| *onth* | *1958* | *1959* | *1960* | *1961* | *1962* | *1963* | *1964* | *1965* | *1966* | *1967* | *1968* | *11-yr mean* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| an | 183.2 | 176.0 | 165.8 | 183.1 | 168.4 | 137.9 | 177.6 | 164.7 | 156.0 | 201.1 | 185.9 | 172.7 |
| eb | 161.3 | 161.8 | 167.2 | 160.4 | 193.3 | 138.9 | 152.4 | 168.1 | 108.3 | 179.9 | 126.8 | 156.2 |
| ar | 180.3 | 177.0 | 148.0 | 188.6 | 178.4 | 164.0 | 156.8 | 178.3 | 146.0 | 174.4 | 143.5 | 166.8 |
| pr | 148.4 | 133.0 | 128.4 | 151.3 | 139.9 | 104.9 | 122.9 | 128.1 | 101.8 | 131.6 | 107.8 | 127.1 |
| ay | 141.5 | 129.5 | 126.8 | 149.1 | 129.8 | 115.4 | 127.7 | 151.7 | 127.0 | 110.4 | 112.8 | 129.2 |
| un | 115.1 | 135.3 | 128.9 | 146.6 | 124.6 | 118.0 | 112.1 | 142.5 | 142.5 | 116.9 | 103.4 | 126.0 |
| ul | 106.5 | 125.6 | 124.0 | 146.7 | 117.3 | 117.2 | 103.5 | 122.3 | 135.1 | 114.8 | 103.9 | 119.7 |
| ug | 117.3 | 134.0 | 133.7 | 129.9 | 126.1 | 120.0 | 106.2 | 124.5 | 134.0 | 121.5 | 110.2 | 123.4 |
| ep | 139.0 | 132.3 | 136.9 | 128.6 | 121.8 | 138.4 | 112.1 | 128.8 | 131.2 | 125.0 | 134.7 | 129.8 |
| ct | 148.9 | 129.8 | 152.2 | 127.6 | 130.8 | 142.4 | 128.6 | 104.3 | 139.7 | 118.7 | 126.6 | 131.8 |
| ov | 153.3 | 128.6 | 142.8 | 109.7 | 143.5 | 116.0 | 133.8 | 100.0 | 145.9 | 113.2 | 120.8 | 127.9 |
| ec | 158.0 | 172.7 | 175.9 | 154.3 | 156.9 | 128.3 | 127.1 | 115.7 | 176.8 | 153.0 | 136.3 | 150.4 |
| *otal* | 1752.8 | 1735.6 | 1730.6 | 1775.9 | 1730.8 | 1541.4 | 1560.8 | 1629.0 | 1644.3 | 1660.5 | 1512.7 | 1661.0 |

o 1968 gave agreement to ±1% on annual totals for both periods. Since virtually all he gauges are set 30 cm above the canopy of the tea, any systematic error due to this xposure will apply to all gauges. The low windspeeds and large drop sizes would robably result in an error considerably less than the 6% for an exposure 30 cm above rass reported from the U.K. by Rodda (1967).

Whilst the programme applied to the meteorological data used essentially the same ersion of the Penman expression (McCulloch, 1965), minor differences resulted in *Eo* alues 3% higher than those from the 10-day mean manual computation. This small orrection, plus the 2.4% and 1.8% corrections to the Lagan and Sambret streamflow rising from the area corrections, account for the minor arithmetic differences etween the present analysis and earlier published values (e.g. Dagg and Blackie, 1965).

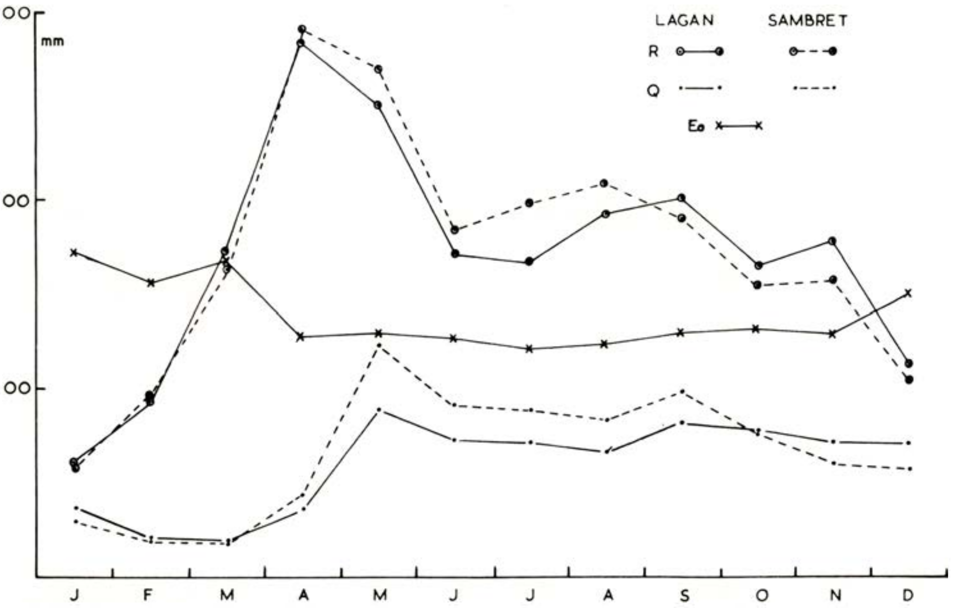

FIGURE 5. *Eleven-year mean monthly values of rainfall, R, and streamflow, Q, for the two catchments and of Penman Eo from the meteorological site.*

The mean seasonal distribution of rainfall, streamflow and Penman *Eo* is illustrated in Fig. 5. Reference to Tables 3 and 4 shows a considerable range about these means between years and between catchments. The *Eo* is much more conservative and its distribution contrasts markedly with typical temperate latitude conditions.

From the 11-year means the annual evapotranspiration is seen to be of the order of 1,300 mm or 0.8 *Eo* for both catchments. To obtain some indication of the year-to-year differences and those between the catchments during the change in land use, it is necessary to apply the water balance expression to shorter periods. To minimise the errors in estimating $\Delta G$ and $\Delta S$ over each period it is preferable to work between times of low rainfall when there is a moisture deficit and the streamflow is on the lower part of the recession curve. These conditions are found most frequently in February. Consequently estimates of evapotranspiration *Et* have been computed for the periods 21 February to 20 February for Lagan and 11 February to 10 February for Sambret, the dates being dictated by the time of soil sampling in each catchment. The results are given in Tables 6 and 7. The crude estimates of water use, $R - Q$, and the ratios $(R - Q)/Eo$ have been included in the tables to provide some comparison of the water-use levels on Sambret during the clearing and planting period when it was not feasible to estimate mean catchment soil moisture deficits. Also included in Table 7 are the data from the forest/bamboo sub-catchment within Sambret. To simplify comparisons the *Et*/*Eo* and $(R - Q)/Eo$ ratios are plotted in Fig. 6.

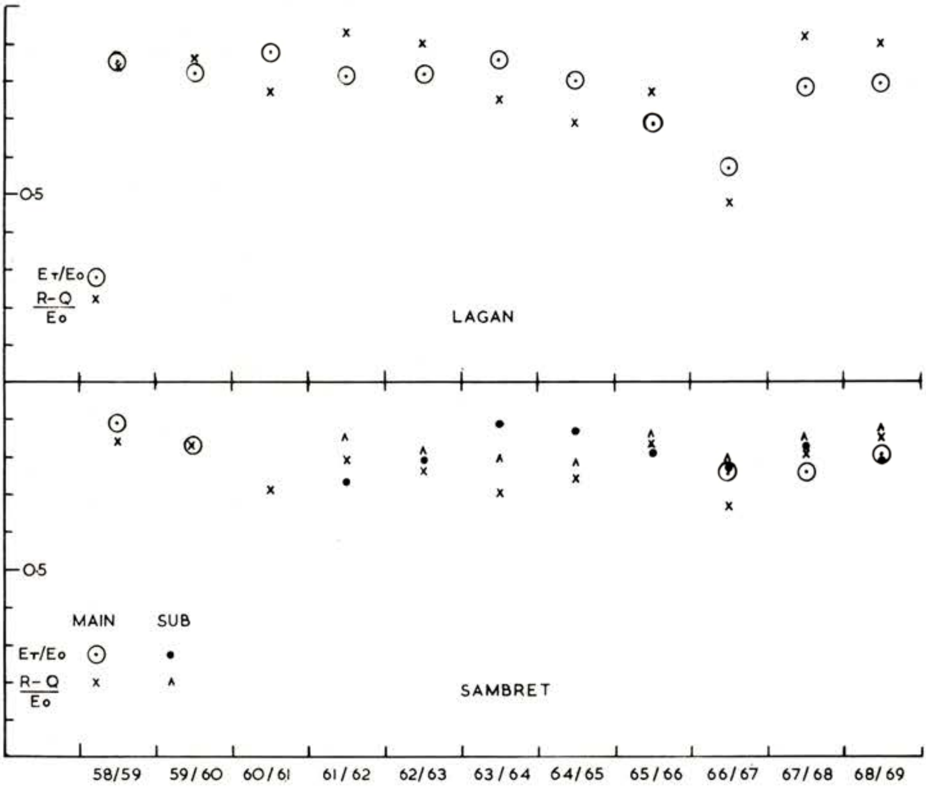

FIGURE 6. *Yearly Et/Eo and (R–Q)/Eo ratios for Lagan and Sambret catchments.*

TABLE 6. Lagan catchment water balance (in mm).

| 21 Feb-<br>20 Feb | $R$ | $Q$ | $E_o$ | $S$ | $G$ | $R-Q$ | $E_t$ | $\frac{R-Q}{E_o}$ | $\frac{E_t}{E_o}$ |
|---|---|---|---|---|---|---|---|---|---|
| 1958/59 | 1788 | 308 | 1765 | -23 | -1 | 1480 | 1504 | 0.84 | 0.85 |
| 1959/60 | 1782 | 297 | 1723 | +59 | +7 | 1485 | 1419 | 0.86 | 0.82 |
| 1960/61 | 2263 | 932 | 1738 | -201 | 0 | 1331 | 1532 | 0.77 | 0.88 |
| 1961/62 | 2660 | 989 | 1794 | +154 | +57 | 1671 | 1460 | 0.93 | 0.81 |
| 1962/63 | 2528 | 1027 | 1659 | +164 | -29 | 1501 | 1366 | 0.90 | 0.82 |
| 1963/64 | 1889 | 700 | 1590 | -170 | -10 | 1189 | 1369 | 0.75 | 0.86 |
| 1964/65 | 1935 | 870 | 1552 | -155 | -16 | 1065 | 1236 | 0.69 | 0.80 |
| 1965/66 | 1488 | 272 | 1588 | +109 | +6 | 1216 | 1101 | 0.77 | 0.69 |
| 1966/67 | 1484 | 647 | 1735 | -147 | -8 | 837 | 992 | 0.48 | 0.57 |
| 1967/68 | 2261 | 780 | 1613 | +175 | +41 | 1481 | 1265 | 0.92 | 0.78 |
| 1968/69 | 2507 | 1164 | 1484 | +173 | -1 | 1343 | 1171 | 0.90 | 0.79 |
| *11-year values* | 22585 | 7986 | 18241 | +138 | +46 | 14599 | 14415 | 0.80 | 0.79 |

TABLE 7. Sambret catchment water balance (in mm). (S = Sambret main catchment, B = sub-catchment.)

| 11 Feb-<br>10 Feb | | $R$ | $Q$ | $E_o$ | $S$ | $G$ | $R-Q$ | $E_t$ | $\frac{R-Q}{E_o}$ | $\frac{E_t}{E_o}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1958/59 | S | 1732 | 246 | 1755 | -70 | 0 | 1486 | 1556 | 0.85 | 0.89 |
| 1959/60 | S | 1898 | 456 | 1731 | -10 | +9 | 1442 | 1443 | 0.83 | 0.83 |
| 1960/61 | S | 2203 | 978 | 1736 | - | 0 | 1225 | - | 0.71 | - |
| 1961/62 | S | 2475 | 1068 | 1776 | - | +61 | 1407 | - | 0.79 | - |
| | B | 2509 | 1014 | | +126 | +65 | 1495 | 1304 | 0.84 | 0.73 |
| 1962/63 | S | 2575 | 1293 | 1680 | - | -20 | 1282 | - | 0.76 | - |
| | B | 2693 | 1323 | | +80 | -30 | 1370 | 1320 | 0.82 | 0.79 |
| 1963/64 | S | 2054 | 940 | 1585 | - | -28 | 1114 | - | 0.70 | - |
| | B | 2274 | 1012 | | -131 | -25 | 1262 | 1418 | 0.80 | 0.89 |
| 1964/65 | S | 2142 | 992 | 1548 | - | -15 | 1150 | - | 0.74 | - |
| | B | 2247 | 1027 | | -113 | -17 | 1220 | 1350 | 0.79 | 0.87 |
| 1965/66 | S | 1622 | 282 | 1606 | - | +9 | 1340 | - | 0.83 | - |
| | B | 1611 | 220 | | +98 | -5 | 1391 | 1298 | 0.87 | 0.81 |
| 1966/67 | S | 1776 | 626 | 1706 | -138 | -9 | 1150 | 1297 | 0.67 | 0.76 |
| | B | 1853 | 658 | | -117 | +6 | 1195 | 1306 | 0.70 | 0.77 |
| 1967/68 | S | 2257 | 931 | 1646 | +61 | +21 | 1326 | 1244 | 0.81 | 0.76 |
| | B | 2290 | 888 | | +25 | +18 | 1402 | 1359 | 0.85 | o.83 |
| 1968/69 | S | 2148 | 888 | 1478 | +73 | -11 | 1260 | 1198 | 0.85 | 0.81 |
| | B | 2305 | 1010 | | +139 | -9 | 1295 | 1165 | 0.88 | 0.79 |
| *11-year values* | S | 22882 | 8700 | 18247 | -88 | +17 | 14182 | 14253 | 0.78 | 0.78 |
| *8-year values* | B | 17782 | 7152 | 13025 | +107 | +3 | 10630 | 10520 | 0.82 | 0.81 |

The *Et*/*Eo* ratio for Lagan remains virtually constant at a mean value of 0.83 for nine of the eleven periods. This provides indirect evidence of the absence of large-scale groundwater loss, *L*, from the catchment on two counts. Energy balance considerations indicate that the potential transpiration rate for an evergreen cover of this type is likely to be of the same order as, or slightly lower than, *Eo*. A figure of 0.83 *Eo* suggests that *Et* is neither grossly under- or overestimated as would be the case if *L* were large. The second consideration is that a positive groundwater loss would fluctuate with rainfall and result in agreement in trend between *Et* and rainfall. The above value of *Et* remains effectively constant through annual rainfalls ranging from 1.0 to 1.7 times *Eo* for Lagan. It can be assumed, therefore, that any groundwater loss from Lagan is small. A groundwater gain, $-L$, would result in an underestimate of *Et*. Whilst the above implies no large gain, the low *Et* values for 1965/66 and 1966/67 could be regarded as evidence of such a gain during these periods only. However, a closer examination of the data suggests that the reduction in *Et* is more likely to have been caused by prolonged and, at times, severe moisture stress. Rainfall was 28% below average in both periods and 6% and 15% less than *Eo*. The number of raindays was below average by 10% and 25% respectively. The distribution of this low rainfall resulted in severe moisture stress developing through February, March and early April 1965 and from December 1966 onwards. In both these dry periods mean deficits of the order of 360 mm in the top 3.2 m were measured. The uneven distribution of streamflow between 1965/66 and 1966/67 also appears to have arisen from the rainfall distribution which resulted in no significant contribution to groundwater until November 1965. In 1966 concentrations of large storms in a few days in April/May and August/September resulted in major contributions.

The magnitude and range of *Et*/*Eo* values for Sambret for the periods before and after the conversion and the trend indicated by $(R - Q)/Eo$ during the conversion imply that no major groundwater gains or losses occurred. During the 1965/66 and 1966/67 dry years Sambret received 130 mm and 300 mm more rainfall than Lagan. This difference appears to have been sufficient to prevent any significant depression of the water use during these periods.

Comparison of the Sambret and Lagan *Et*/*Eo* figures for the short pre-clearing period shows agreement within 5%. For the Sambret forest/bamboo sub-catchment the 1961-69 value of *Et*/*Eo* is 0.81 as compared with the 9-year value of 0.83 for Lagan. These figures imply that no significant long-term difference exists between the evapotranspiration rates of the pure forest and mixed forest bamboo cover in this climatological environment.

For the clearing and planting period comparison of the water use must be based on the $R - Q$ figures. These give $(R - Q)/Et$ ratios of:

| | | |
|---|---|---|
| 1960-64 | Lagan | 0.84 |
| | Sambret | 0.74 |
| 1961-64 | Lagan | 0.86 |
| | Sambret | 0.75 |
| | Sub-catchment | 0.82 |

The apparent 11% reduction in water use may seem small in relation to a clearing o over 50% of the catchment, but by the end of 1963 the young tea bushes on the firs cleared area were growing rapidly. It is estimated that the mean effective bare soil are of the catchment never exceeded 30% of the total area. A mean evaporation rate o 0.45 *Eo* from such a bare soil area would account for an 11% reduction in the tota catchment evapotranspiration. With 240 raindays in the year bare soil evaporation a this rate is feasible.

For the 1968/69 period when even the youngest tea was approaching its mature level of ground cover the *Et*/*Eo* figure for Sambret was 0.81, as compared with 0.79 for the sub-catchment and for Lagan. For the same period a lysimeter study at the adjacent Tea Research Institute gave a mean *Et*/*Eo* value 0.79 for 3-year-old tea (Dagg, 1970). The agreement between this and the Sambret figure provides further evidence of the absence of any major systematic errors in the catchment data.

A summary of the stormflow pattern throughout the 11 years is presented in Table 8. The figures are monthly stormflow totals expressed as percentages of monthly rainfall. Only months for which the water level recorders were 100% operational are included. The outstanding feature is the very low level of the stormflow from both catchments. The average value for the forested catchment over the 11 years is only fractionally over 1% or some 22 mm per year. During clearing and planting the Sambret value rose by over 100% to over 2% of the rainfall. The individual storm study (Dagg and Blackie, 1965) showed a maximum rise to 5.6% for storm intensities over 50 mm/h. From 1965 onwards the level dropped again to 1%. Since runoff from the housing area and the road system is greater than from the forest the 1965/68 figures imply that the tea gardens form an even more efficient flood control cover than the forest on these highly permeable soils.

TABLE 8. Monthly storm runoff as a percentage of monthly rainfall for Sambret (S) and Lagan (L).

| | | *1958* | *1959* | *1960* | *1961* | *1962* | *1963* | *1964* | *1965* | *1966* | *1967* | *1968* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | S | 0.5 | - | 1.0 | - | 1.2 | 0.8 | 0.0 | 0.5 | 0.2 | 0.0 | 0.0 |
| | L | 0.6 | 1.1 | 1.0 | - | 1.3 | 0.8 | 0.0 | 0.7 | 0.8 | 0.0 | 0.0 |
| Feb | S | 1.4 | - | 0.5 | - | 0.9 | 1.1 | 0.0 | 0.0 | - | 0.0 | 0.4 |
| | L | 1.5 | 0.8 | 0.6 | 0.0 | 0.9 | 0.6 | 0.0 | 0.0 | 1.3 | 0.3 | 0.8 |
| Mar | S | 1.7 | - | - | - | 2.6 | 1.1 | 0.0 | 0.7 | 0.8 | 0.0 | 0.3 |
| | L | 2.0 | 1.2 | 1.0 | 0.7 | 0.9 | 1.1 | 0.0 | 0.7 | 1.0 | 0.7 | 1.2 |
| Apr | S | 0.7 | - | - | - | 2.1 | 1.5 | 1.5 | 0.9 | 1.4 | - | 1.1 |
| | L | 0.9 | 0.8 | 1.5 | 0.9 | 1.0 | 1.1 | 1.6 | 0.8 | 1.2 | 0.9 | 1.1 |
| May | S | 1.4 | - | - | - | 3.9 | 2.6 | 1.0 | 0.7 | 1.2 | 0.8 | - |
| | L | - | 0.6 | 1.8 | 1.4 | 1.5 | 1.2 | 1.4 | 0.9 | 0.9 | 0.6 | 1.2 |
| Jun | S | 1.2 | - | - | 1.2 | 1.2 | 1.0 | 0.8 | 0.7 | 1.0 | - | - |
| | L | 1.2 | 1.2 | 1.8 | - | 1.3 | 1.1 | 1.7 | - | 0.8 | 0.2 | 0.7 |
| Jul | S | 1.1 | - | - | 0.7 | 1.6 | 1.9 | 2.8 | 0.5 | 1.6 | - | 1.3 |
| | L | 1.1 | 0.8 | 1.7 | 1.1 | 1.3 | 1.2 | 1.9 | 0.9 | 0.5 | 0.2 | 0.7 |
| Aug | S | 1.1 | - | - | 1.6 | 2.3 | 1.7 | 1.7 | 0.6 | 0.9 | 0.4 | 0.8 |
| | L | 1.1 | 0.9 | 1.0 | 1.0 | 1.2 | 1.3 | 1.3 | 1.4 | 1.0 | 1.0 | 1.1 |
| Sep | S | 0.5 | - | 3.3 | 1.8 | 1.5 | - | 2.5 | 0.1 | 1.8 | 0.9 | 0.5 |
| | L | 1.1 | 1.2 | 1.7 | 1.0 | 1.2 | 1.4 | 1.3 | 0.8 | 1.8 | 0.4 | 1.0 |
| Oct | S | - | - | 1.6 | 1.0 | 2.1 | - | 3.0 | 1.1 | 0.4 | - | - |
| | L | 1.5 | 0.9 | 1.8 | 1.0 | 1.1 | 1.1 | 2.1 | 1.1 | - | 0.7 | 0.5 |
| Nov | S | - | 2.0 | - | 1.8 | 0.5 | 0.8 | 0.6 | 2.0 | 0.0 | 1.1 | 0.5 |
| | L | 1.0 | 1.2 | 1.6 | 1.4 | 0.7 | 0.6 | 0.7 | - | 0.0 | 1.0 | 0.6 |
| Dec | S | - | 0.2 | - | 2.0 | 1.4 | 1.1 | 0.7 | 3.7 | 0.0 | 1.3 | 0.4 |
| | L | 1.2 | 1.1 | 0.0 | 1.7 | 0.9 | 0.5 | - | 1.0 | 0.0 | 1.5 | 0.6 |

## CONCLUSIONS

From the evidence presented it is concluded that the catchments are effectively watertight and that the results obtained are valid within the limits of accuracy indicated for the rainfall, streamflow and soil moisture measurements.

The water use of the forested control catchment was found to be 79% of Penman potential open water evaporation for the 11 years. If two years during which the catchment was subject to severe moisture stress are excluded, this figure becomes 83%. The figure of 81% for the water use of the sub-catchment under a mixed bamboo and forest cover within the experimental catchment is not significantly different from that from the forest. Water use of the experimental catchment under its initial forest and bamboo cover was effectively the same as that from the control catchment. The level dropped by some 10% during the 4-year period in which half of the catchment was progressively cleared and planted to tea. Five years after the final planting when the tea was very close to its mature level of ground cover, the annual water use of the experimental catchment was within 2% of that from the control catchment and the sub-catchment.

Storm runoff from these catchments is remarkably low at some 20 mm per year or fractionally over 1% of the incident rainfall. Clearing and planting doubled the runoff rate from the experimental catchment to over 2%, but this dropped again to its previous level as the tea gardens matured.

From the downstream users' viewpoint the critical factor in catchment performance is the dry season water yield. Increases in either the evapotranspiration rate or the storm runoff level in the catchment will result in a reduction of this yield. The interim conclusion from this study is that, within the limits of accuracy of the measurements, the land use change from forest to tea plantation caused a minor change in yield during the transition period, but five years after final planting no significant difference from the original yield could be detected.

It is necessary to continue the study until the tea reaches maturity before a final conclusion on the effect of the change can be reached. In an effort to increase the accuracy of the measurements and to obtain water use figures over shorter periods, soil moisture sampling in both catchments is now being done on an expanded network using neutron moisture meters, more sensitive water-level recorders have been installed, and automatic weather stations will be used to measure the meteorological parameters for the Penman estimate within the catchments. A radiation balance study over the different vegetation types planned for January 1971 should yield further evidence on the validity of the $Et/Eo$ ratios obtained.

The interim conclusion applies to the effects of this land use change when carried out on stable highly permeable soils under the climatic conditions described. Due consideration must be given to these factors before extending it to other areas.

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