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HYDROLOGY AND AFFORESTATION IN THE ABERDARES

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Water is a vital natural resource in East Africa, whether in the form of rain, surface or ground water. The seasonal amount of rain is often the limiting factor in agricultural production and the presence or absence of surface water in many cases determines the extent of human habitation. Even in areas where rainfall is adequate for settled agriculture, perennial surface water supplies are essential for domestic and stock requirements. Where irrigation schemes are in operation or planned, their success depends on a particular minimum flow of water in the river. The areas in East Africa that give rise to perennial streams are very limited in extent and the judicious management of the land in these areas is of paramount importance in maintaining surface water resources.

One such area of high rainfall is the Aberdare range in Kenya, the southeastern end of which gives rise to a number of important streams providing domestic and stock water supplies for the densely populated agricultural region of the Kikuyu and for the rapidly growing city of Nairobi, besides supplying water for the processes involved in the production of high quality *arabica* coffee from the intensively developed plantations further downstream. Much of this area also drains into the Tana River, which is earmarked for the development of large-scale irrigation schemes. The indigenous vegetation of the southern Aberdares is montane forest giving way to bamboo forest at appromixately 7,500 ft., with giant heaths and moorland species coming in on the high tops above 10,000 ft. The average annual rainfall ranges from about 60 inches to 90 inches. There are few trees of commercial value to be found in these forests but the Kenya Forest Department has shown that pines can be grown in the bamboo zone to mature in 30 years or less. The area therefore, offers considerable potential for the establishment of a large-scale timber industry.

The development of a pine forest involves preliminary clearing and burning of the bamboo on the flat and gently sloping land, followed by cultivation of vegetable crops among which, at the end of the first year, the young pine seedlings are planted; after a period of two to three years the growing pine canopy makes further arable intercropping impracticable. These proposals provoked trenchant criticism with regard to the hydrological consequences of such a major land-use change. It is known that a continuous and undisturbed vegetative cover provides the maximum natural control of surface water, and by maintaining the permeability of the topsoil, ensures the optimum recharge of soil moisture and hence the ground water reservoir on which continuity of dry weather streamflow depends. It was argued that extensive clearing of the catchment areas and cultivation of the rather unstable, humic, ash-derived soil would inevitably result in increased run-off and eventually in disastrous flooding downstream and that the consequent erosion would adversely affect the quality of the water. Further, it was thought possible that the amount of water transpired by the pines would be greater than that used by the indigenous bamboo. In the absence of quantitative information on which to assess the danger of these effects in relation to the undoubted economic benefit of the land-use change, the matter was subjected to direct experimentation.

At a conference of specialists from the three East African territories held at the East African Agricultural and Forestry Research Organisation headquarters in 1956, it was decided that, in view of the range of scientific and practical skills required in catchment area experiments, such projects could best be controlled by a central research organisation working in co-operation with the territorial Departments. Four projects involving land-use change were proposed and it was agreed that the central organisation should be the responsibility of the Physics Division, E.A.A.F.R.O. The initiation of each project and the subsequent routine field-work would be carried out in conjunction with the Forestry, Agricultural and Water Engineering Departments of the country in which it was situated while the laboratory work and the analysis of data would be done at E.A.A.F.R.O.

The classical method of catchment area research developed in the United States of America provides for the derivation of statistical relations between rainfall and streamflow for a catchment over a period of about 15 years. The land-use is then changed and a new relation derived over the next 15 years, or longer, depending on the period required to establish the new form of land-use. This time scale was considered inappropriate in face of the urgency of the problems in East Africa and a much more intensive method of study had to be evolved.

The hydrological cycle of a catchment is illustrated in Fig.1; the two factors most likely to be affected by a change in the vegetative cover are the amount of rainfall lost as surface run-off and hence as stormflow, and the amount of water transpired. The consequences of changes in these factors are integrated in the pattern of streamflow into the year-round "baseflow" derived from ground water and additional stormflow in the rainy season. The effect of an increase in surface run-off will be to increase the wet season stormflow at the expense of accumulation of moisture in the soil and hence of the base flow in the dry season; the effect of an increase in transpiration will be to cause an overall decrease in streamflow, particularly in baseflow. The combination of increased run-off and increased transpiration will, in extreme cases, result in the total disappearance of the stream in the dry season. Thus the factors to be studied extensively under both bamboo and pine covers are the rate of transpiration from the canopy and the stormflow response to rainfall of the catchment.

It is difficult to measure directly the amount of water transpired by the vegetative cover of a catchment. An approximate annual total can be obtained from the difference between rainfall input and streamflow provided the 'water year' is chosen between times when the amounts of water in the soil and in deep storage are likely to be similar. The accuracy can be increased if changes in soil moisture are measured by direct sampling. Since transpiration is controlled by weather conditions the annual total for any cover will vary from year to year and from place to place. These annual totals therefore, can not be used to compare the water use of the two covers unless the two catchments are adjacent and so exposed to the same weather conditions. However, research in England by Penman has indicated that the rate of transpiration from a continuous canopy of evergreen vegetation well supplied with water, like evaporation from open water, is almost completely determined by the meteorological environment. Thus if open water evaporation is estimated from meteorological observations taken

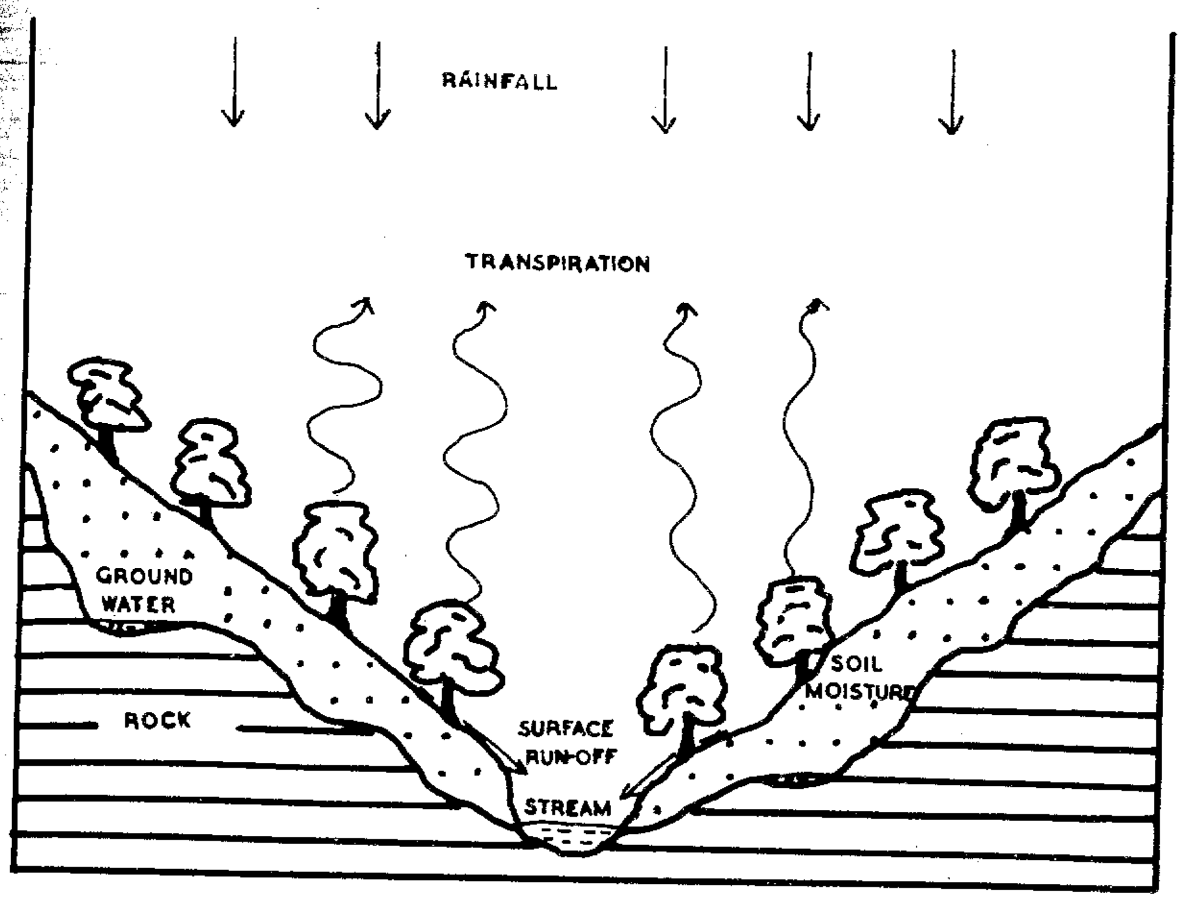

FIGURE 1.

THE HYDROLOGICAL CYCLE

close to the catchments, the value of the ratio of measured transpiration, E_t, to estimated evaporation, E_o, obtained from the annual totals, will provide a constant which describes the transpiration rate of the cover irrespective of place or weather conditions. To obtain statistical relationships between a rainfall parameter and stormflow by the classical methods would require data from a large number of wet seasons. If the total rainwater input into the catchment is known sufficiently however, precise relationships can be obtained in a much shorter time by studying the response of the catchment to individual storm characteristics such as rainfall intensity, and moisture status of the surface soil.

Two small similar catchments under bamboo were selected close to Kimakia Forest Station. The Geological Survey of Kenya indicated that the chances of deep seepage losses occurring were small and so the installation of the equipment began in 1956. Compound V-notch weirs, designed by the Hydrology Section of Kenya Ministry of Works were sited and built at the outfalls of the catchments, and were equipped with sensitive autographic water level recorders. A carefully stratified network of raingauges was laid out to give a coverage of better than one gauge to ten acres. Since clearings for these gauges would have altered the cover, they were installed at canopy level in the bamboo, either on towers or on platforms mounted on convenient trees. A meteorological site was equipped with the instruments necessary to give data for the calculation of open water evaporation using the Penman equation. Detailed general, ecological and soil surveys were made. Samples of the soils were studied in the Physics Division laboratories to obtain accurate information on the water holding capacity of the soil within the root range of the cover and sampling sites were selected from which regular soil moisture data would be obtained Electrical soil moisture measuring equipment was also installed at each of these sites so that the changes in moisture content between the regular sampling dates could be followed.

One catchment was converted to pines while the other remained under bamboo as a control. The routine daily observations are carried out by a team of observers appointed jointly by E.A.A.F.R.O. and the Forest Department. All data is sent to the E.A.A.F.R.O. Physics Division for analysis and officers from there make frequent tours of inspection of the equipment while the Forest Officer at Kimakia attends to the protection and general maintenance of the catchments. A detailed description of the establishing of this and the three other catchment area research projects together with a preliminary analysis of the data obtained in the first three years was published in the Special Issue of the *East African Agriculture and Forestry Journal* of March, 1962. Some indication of the results obtained to date from this experiment are given in the following paragraphs:–

(a) For the bamboo control catchment the mean value of the ratio of transpiration to evaporation, the E_t / E_o ratio, obtained from five sets of annual totals has been $E_t / E_o = 0.85$. This figure has been remarkably constant over the five years' observations and has been confirmed from results of soil moisture sampling.

(b) During the first three years the cleared catchment was under a mixed cover of young pines and vegetables with considerable areas of bare soil exposed. Since the rate of evaporation from a dry soil surface is low, the amount of water evaporated and transpired was very much lower than it has been under the bamboo. This resulted in an overall increase in streamflow. The E_t / E_o ratio for the first water year was $E_t / E_o = 0.44$.

(c) As the pines have grown, the percentage of ground covered has increased and the ratio has gradually risen, The trees are now 25 ft. high and the cover is virtually complete. The latest figures give $E_t / E_o = 0.91$.

As the annual E_o for this area is remarkably constant at close to 50 inches the pines therefore appear to use some 3 inches more of the annual rainfall than the bamboo at this stage. This, in terms of the average annual streamflow under a rainfall regime of some 90 inches, infers a diminution in water yield of 6%.

The study of the rainfall, run-off relationships of the two catchments yielded some surprising results. From the control catchment the annual surface run-off was found to be 1.8% of the total rainfall while the pine catchment yielded only 1.3%. The response to individual storms was found to vary with the total rainfall, with the moisture condition of the surface soil and with the rate at which the rain fell. For the control catchment the response under wet surface conditions was from 1.5% of the storm total for storms of intensity less than ½ inch per hour to 3.5% for intensity greater than 1½ inches per hour while under dry conditions no run-off occurred from storms of less than 0.4 inches. For the planted catchment the response to the varying intensities under wet surface conditions ranged from 1% to 3.5% of the storm totals. These relationships were derived from the 1959–60 figures when the pines were over 15 ft. tall and cultivation was about to stop. Analysis of the 1957–58 data when cultivation between the pines was intense revealed that the situation was similar then. This remarkably low run-off from the cleared catchment was contrary to experience elsewhere; its explanation appeared to lie in the extremely high permeability of these soils.

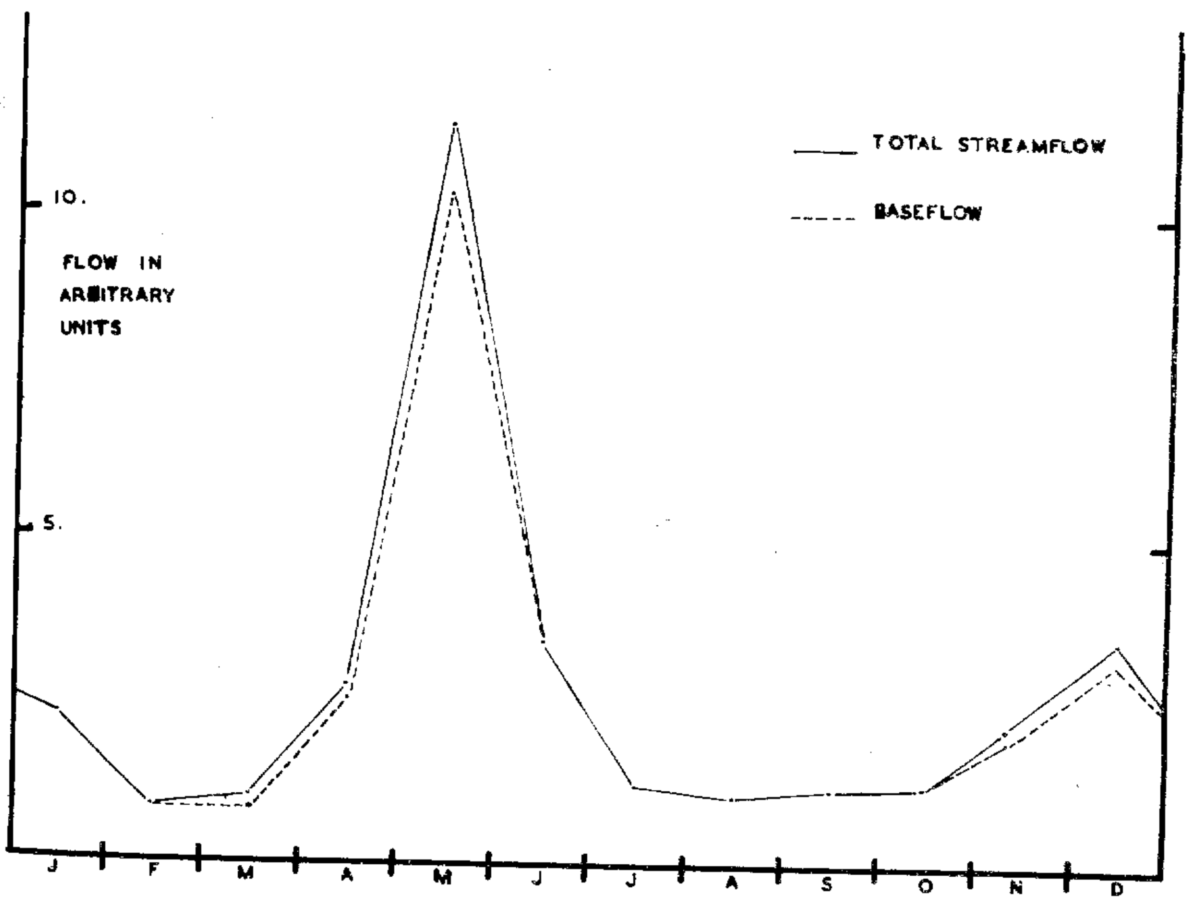

FIGURE 2.

TYPICAL SOUTHERN ABERDARE STREAMFLOW PATTERN

A study was also made of the effects of the conversion on the quality of the water. Routine daily sampling of the streams indicated that the quality of the water from the bamboo catchment was extremely high, the suspended sediment being only of the order of 60 parts per million. While the pine catchment was being cultivated the quality dropped considerably. In May, 1960, the suspended sediment reached an extreme value of 625 p.p.m. representing a loss of soil from the catchment of nearly half a ton per acre per annum. As soon as cultivation stopped however, the quality of the water returned to a level comparable to that of the bamboo catchment.

The results obtained to date thus indicate that streamsource areas in the forest zone of the Aberdares can be planted with commercially valuable timber and retain the hydrological situation that prevailed before the land-use change. During the conversion to pines, no increase in surface run-off occurred although the quality of the water was temporarily reduced. The water use of the mature pines has yet to be determined; the present trend suggests that it will be only slightly higher than that of the bamboo. Another feature of the conversion which may adversely affect the streamflow will be the felling operation when the crop is mature. The roads and tracks of the sawmillers will probably have considerable effect on surface run-off, but the study of this effect will have to wait for at least another twenty years.