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PROBABLE MAXIMUM PRECIPITATION (PMP) IN EAST AFRICA FOR DURATIONS UP TO 24 HOURS

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PMP for durations up to 3 hours

For East Africa, the PMP over an area of about 10 km^2 for durations up to 3 hours has been calculated by Sansom (1). Using a thunderstorm model appropriate to East Africa, he derived the values:

$$\text{PMP in 1 hour} = 3W_e$$

$$\text{PMP in 3 hours} = 6W_e$$

where W_e is the "effective precipitable water", i.e. the depth of water which can be precipitated from a given column of the atmosphere. It varies with ground elevation and wet-bulb potential temperature whose maximum value over East Africa is taken to be 26.7°C (i.e. 80°F). Values of W_e for a wet-bulb potential temperature of 26.7°C (80°F) are given below for elevations of 0, 3000, 5000, 7000 and 9000 feet.

Elevation (feet)	W_e (mm)
0	53
3000	43
5000	36
7000	30
9000	25

As a check on the expressions $3W_e$ and $6W_e$, the highest rainfall ever recorded in East Africa in 1 hour (112 mm) and in 3 hours (246 mm) occurred at Entebbe (where autographic records commenced in 1938) during a severe thunderstorm on 31st May 1958. At the elevation of Entebbe (3878 feet) $3W_e$ is 116 mm and $6W_e$ is 233 mm. The measured values are point rainfalls, and a recent investigation in England (2) of the relation between point and areal rainfall for showery precipitation indicates that point rainfalls for 1 to 3 hours duration can be expected to be 15 to 10% higher than the areal rainfall over 10 km^2. Assuming this relation holds good for convective rain in East Africa, the extreme values so far recorded are in good agreement with Sansom's estimate of PMP for 10 km^2.

PMP for durations 3 to 24 hours

In order to calculate the PMP for periods up to 24 hours, we can make use of the relation between maximum rainfall intensity (I) and time t up to 24 hours for stations in East Africa found by McCallum (3), namely:

$$I = I_1 t^{-n} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

where n and I_1 (maximum intensity over 1 hour) are constants.

The rainfall (R) in t hours is

$$R = It \quad \ldots \quad (2)$$

Eliminating I we get

$$R = I_1 t^m \quad \ldots \quad (3)$$

where $m = 1-n$.

Since the general equation (3) should apply to the special case where R = PMP, we get:

$$\frac{\text{PMP for t hours}}{\text{PMP for 3 hours}} = \left(\frac{t}{3}\right)^m \quad \ldots \quad (4)$$

or, $$\text{PMP for t hours} = 6W_e\left(\frac{t}{3}\right)^m \quad \ldots \quad (5)$$

for $3 \leqslant t \leqslant 24$ hours.

Hence for any given ground elevation we can use equation (5) to calculate the PMP for any value of t between 3 and 24 hours provided the appropriate value of m is known, and the curve relating PMP and t can be extended to the origin by using the relation PMP in 1 hour = $3W_e$.

Discussion of the value of m

Inland areas

For ten inland stations for which suitable records were available, McCallum found values of the index n varying between 0.79 and 1.00. Hence m varies between 0.21 and zero. Since we are concerned with maximum precipitation, the value 0.21 has been adopted for inland areas, and equation (5) for inland areas becomes:

$$\text{PMP for t hours} = 6W_e\left(\frac{t}{3}\right)^{0.21} \quad \ldots \quad (6)$$

Using equation (6) with appropriate values of W_e, curves relating PMP to t for elevations of 3000, 5000, 7000 and 9000 feet have been drawn (see Figure 1).

Storm at Sigona, April 1967

A recent storm at Sigona (April 1967) is of special interest, since it gave the highest 24-hour rainfall yet recorded in the Nairobi area since 1934 (the first year for which records of annual maximum 24-hour rainfalls are readily available). At Sigona (1° 12'S, 36° 39'E) 248 mm of rain fell, and during the same storm 216 mm was measured at Muguga (EAAFRO, 1° 13'S, 36° 38'E) where an autographic raingauge is installed. Assuming the same proportion of the total

rainfall fell in given intervals of time at these two neighbouring stations, the maximum falls at Sigona would have been 139, 213, 239 and 248 mm in intervals of 3, 6, 12 and 24 hours respectively. These points, marked S, have been plotted on Figure 1, and since Sigona's elevation is 7000 feet it is seen that the rainfall totals are very close to the calculated PMP.

East African Coast

At the Coast, the rainfall regime is different from that at inland stations. This is shown by the I/t relations found by McCallum for Mombasa and Dar-es-Salaam, viz.:

Mombasa $I = 56\, t^{-0.55}$ .. .. (7)

Dar-es-Salaam $I = 58\, t^{-0.62}$ .. .. (8)

where I is in mm/hr

The relatively small index values of 0.55 and 0.62 at the Coast can be explained by the fact that prolonged heavy thunderstorms at the Coast are rare, and heavy rain lasting for upwards of one hour is more frequently the result of a disturbance in the monsoon. Equations 7 and 8 give a rainfall in 3 hours of 102 mm and 115 mm respectively, whereas the physical upper limit on Sansom's thunderstorm model is $6W_e$ = 318 mm. Therefore the adoption of equation (6) for the Coast would almost certainly give absurdly high values for durations greater than 3 hours.

A sounder approach to the problem is to make use of Sansom's assessment of the maximum rainfall to be expected at the Coast in a tropical cyclone. Using data for the cyclone that struck Lindi in April 1952, applying moisture adjustment to the observed rate of rainfall to give the rate that would have occurred had the wet-bulb potential temperature been 80°F, and assuming heavy rain could continue for a period of 10 hours, the PMP in 10 hours is found to be 330 mm.

As regards the appropriate value of m, since we are concerned with maximum rainfall the larger value of n (for Dar-es-Salaam) = 0.55 has been chosen, and equation (6) for coastal areas becomes:

$$\text{PMP in t hours} = 330\left(\frac{t}{10}\right)^{0.45}$$

The resulting curve relating PMP and t is shown in Figure 2.

The highest 24-hour rainfall yet recorded at the coast since 1934 is 404 mm at Vanga (4° 40'S, 39° 12'E) in October 1966. This point is plotted on Figure 3. The highest 1-hour and 3-hour rainfalls yet recorded at the coast occurred at Chukwani, Zanzibar. These are also plotted on Figure 3. All three points lie fairly close to, but underneath, the curve.

A check on the curves of Figure 1

From records issued by the E.A. Meteorological Department, of maximum 24-hour falls for approximately 2000 rainfall stations during the period 1934 – 1966, I noted all occasions when the fall exceeded 235 mm (the calculated PMP for elevation 9000 feet). These rainfalls have been plotted on Figure 3, taking into account the elevation of the station. The curve in Figure 3 relates

PMP in 24 hours to elevation. It is seen that only four 24-hour rainfalls are significantly greater than the calculated PMP for the appropriate elevation. Two of the exceptions occurred in the Meru area and one in the Nyeri area. The Meru stations are on the eastern slopes of Mount Kenya, and the Nyeri station is on the eastern slopes of the Aberdares, so that the deep prevailing easterly winds of the rainy seasons are subject to considerable orographic uplift in the vicinity of these stations. If the airmass is characterised by potential instability, prolonged rainfall, moderate or heavy at times, can occur, and the curves of Figure 3 are no longer applicable. A separate study of rainfall records would be required in order to arrive at an estimate of PMP for areas where orographic uplift during the rainy seasons is important.

As regards the phenomenal 24-hour rainfall at Tukuyu, this station is in a peculiar region of very high annual rainfall (exceeding 2500 mm) in the extreme south of Tanzania, between the Poroto Mountain and Lake Nyasa. This region would appear to have a rainfall regime very different from that of the 10 inland stations from which the value of m = 0.21 in equation (6) was derived. A separate study of rainfall records for this area would be necessary in order to make an estimate of the PMP.

REFERENCES

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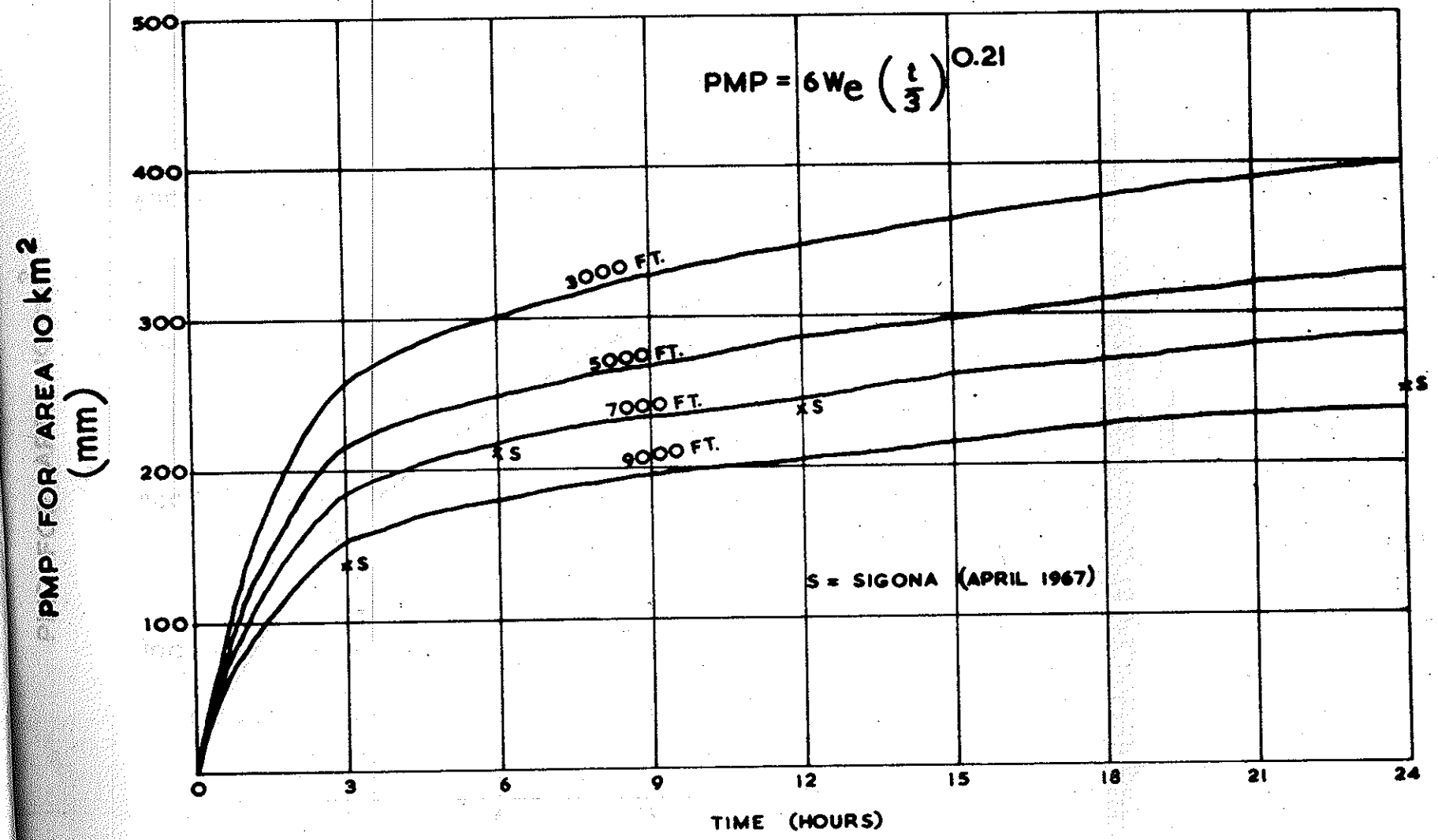
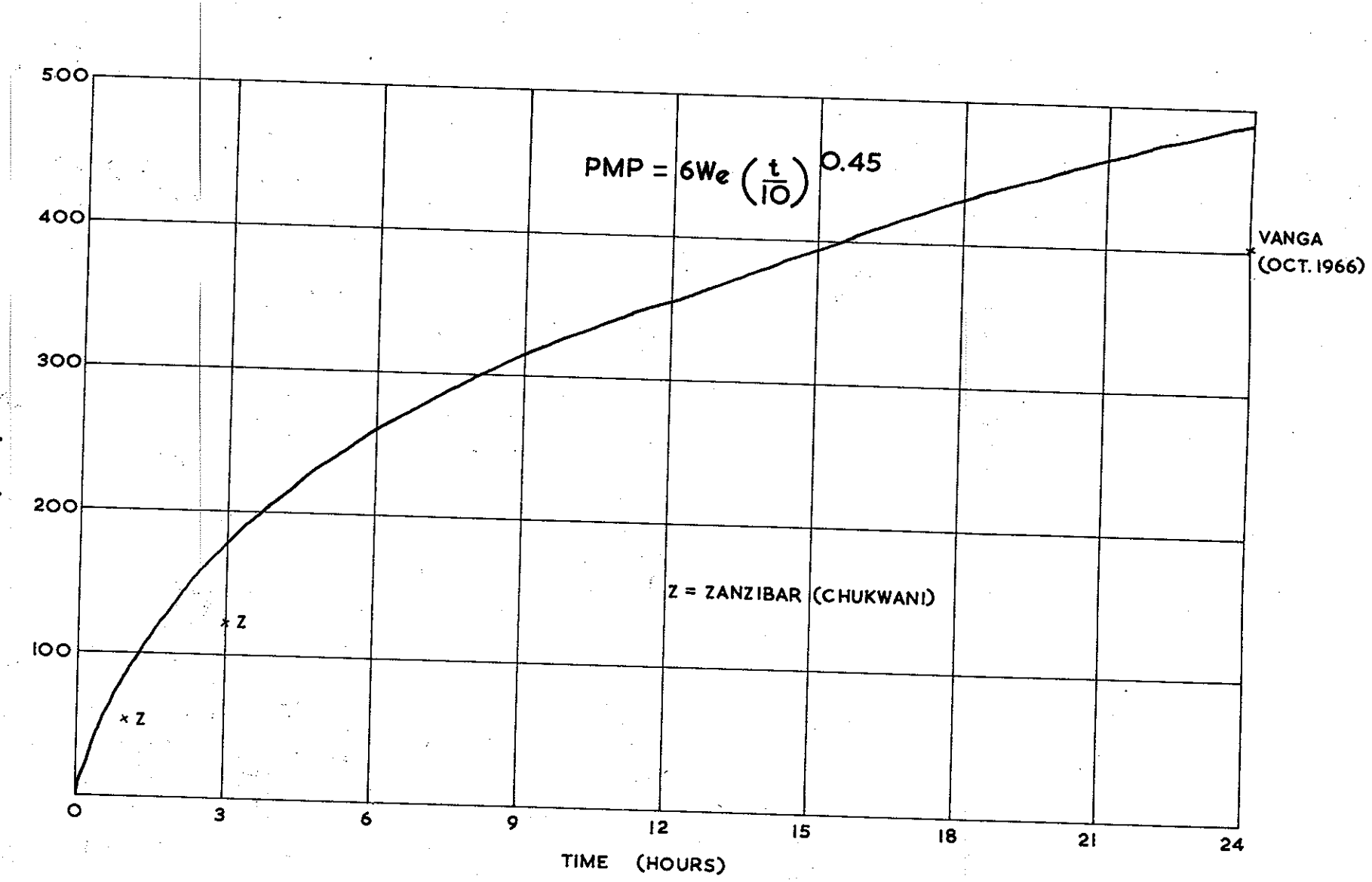
3. McCallum, D. (1959) — The relationship between rainfall intensity and time; 6 p., 6 charts (E.A.M.D. Mem. Vol. III, No. 7).



PMP FOR INLAND AREAS

FIGURE 1



PMP FOR EAST AFRICAN COAST

FIGURE 2

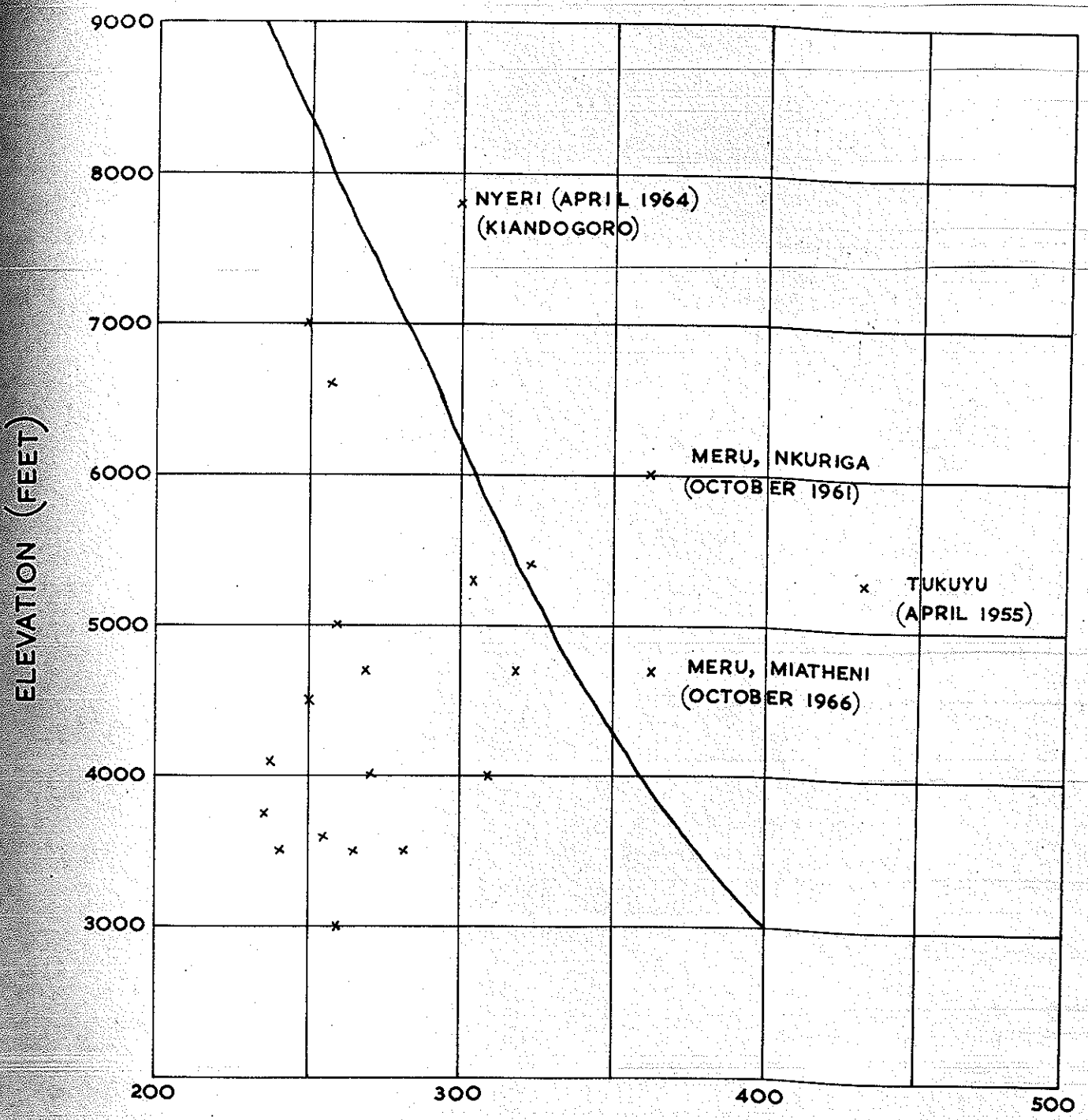

9000
8000
7000
6000
5000
4000
3000
200
300
400
500
ELEVATION (FEET)
PMP IN 24 HOURS (mm)
NYERI (APRIL 1964)
(KIANDOGORO)
MERU, NKURIGA
(OCTOBER 1961)
TUKUYU
(APRIL 1955)
MERU, MIATHENI
(OCTOBER 1966)

FIGURE 3