Hydrology in Lesotho

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Mr R. B. Bulman, Consultant

With diurnal variations of the order of 40–50%, as quoted in § 16, there are dangers in computing and publishing values of mean relative humidity. There will be considerable differences between saturation deficits calculated from mean relative humidity and true values of mean saturation deficits. Penman-type estimates based on the former will be in error. There are advantages in publishing the averages of daily maximum relative humidity and the averages of daily minimum relative humidity. From these it is possible to make a better estimate of mean saturation deficit.[12] Better still, mean saturation deficit should be computed directly from the basic data when hourly values are available.

39. Variation of annual precipitation with altitude as illustrated in Fig. 5 is of special interest when assessing water resources from sparse data. Has the Author observed any similar tendency in the case of intense rainfall with durations of the order of 24 hours? Such information would be of great assistance in flood studies and worth publishing as more data become available.

40. It is understood that Fig. 6 is based on data for the Republic of South Africa, but could the Author give the following data for Maseru and Oxbow

(*a*) average or median values of annual maxima of 24 hour rainfall
(*b*) highest recorded value of annual maximum 24 hour rainfall
(*c*) number of years' records on which (*a*) and (*b*) are based
(*d*) station elevation.

Some regions elsewhere appear to indicate a lapse rate for intense rainfall contrary to the pattern of annual precipitation.

41. The temptation to look for well-defined correlations between flow records and total rainfall (§ 24) should be resisted. If based on short records they will be misleading and in any case must not be extrapolated. When sufficient data are available the rainfall records may be analysed as in chapter VI of reference 12. It will then be more fruitful to consider correlations between flow records and excess rainfall.

42. Could the Author define the term 'mean annual flood' in Fig. 10 and § 25? Would not 'average of annual peaks' be more appropriate? If there were a return to the old-fashioned idea of reserving 'mean' for use in connexion with a continuous variable, some ambiguities in current hydrologic literature could be avoided. The sum of a number of discrete values divided by that number would then be denoted by 'average'.

43. Paragraph 25 also refers to Fig. 7, which relates to mean annual runoff. The left bank tributaries have a lower mean annual runoff and so it would not necessarily follow that they would also have lower averages of annual peaks.

Mr A. R. Porter, F

My interest in the Paper lies in the evaporation studies at Maseru and Oxbow. I am pleased that the pans used were the US Weather Bureau class A type; in other countries there are a number of different types of pan in use and this makes the comparative evaluation of results difficult. In the USA there are more class A pans in use than elsewhere, with long records too, and it would be as well if other countries extended their use and also operated them alongside existing pans to determine correction factors.

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45. In Ghana, during the investigation for the Volta River Project, with which I was associated, and where other types of pan had been in use at 21 stations, examples of each type were set up at a station in Accra, together with class A pans, screened and open, for this purpose. At Port Moresby in Papua I arranged for the installation of a class A pan alongside an existing Australian standard pan with a long record.

46. In the records of the two pans at Maseru and Oxbow shown in Fig. 4 the temperature of the pan water is omitted. This is needed for the evaluation of the pan/lake ratio or pan factor in order to convert pan evaporation to the equivalent open water evaporation at the same place. A pan cannot reflect the energy storage changes in such a lake; moreover, heat exchange through the pan sides causes this factor to vary.

47. Max Kohler and his colleagues at the US Weather Bureau, following studies at lakes Hefner and Mead, showed that by using the temperature differences between the air and the pan water the pan factor could be adjusted for this heat exchange, and they produced a graphical method for processing their calculations to give a hypothetical lake evaporation. This allows for the proportion of advected energy into the pan used for evaporation, but there still remains a small adjustment to be made for the energy storage change and advection of energy in the lake, which of course can only be applied when the lake exists.

48. The studies also showed that pan evaporation could be reliably estimated, given the air and water temperature, the dew point and the wind speed. This operation can be expressed by

$$E_p = (e_o - e_a)^{0\cdot88}(0\cdot547 + 0\cdot00376U_p)$$

where e_o and e_a are the respective aqueous vapour pressures at the water surface and air temperatures in millimetres of mercury and U_p is the daily run of wind at pan height in kilometres. E_p is then the daily pan evaporation in millimetres.

49. I have applied this equation to some known pan figures. At Boulder City on Lake Mead it gives an annual pan evaporation of 2805 mm compared with an actual 2785 mm, at Boulder Island 3417 mm compared with 3440 mm, at Port Moresby 2110 mm compared with 2095 mm (these with less than 1% bias) and at Accra 1765 mm as against 1740 mm (a 1·5% bias).

50. An exercise of Kohler's further process of deriving the hypothetical lake evaporation produces from the pan 3440 mm at Boulder Island (on the lake itself), 2210 mm for the lake compared with 2160 mm obtained from a water and energy budget. The figure was reduced by 110 mm to account for changes in energy storage and advection.

51. This equation is reversible, and where there are no water temperatures, as at Maseru and Oxbow, they can be estimated by working backwards from the pan figures, and then, using Kohler's process, the equivalent lake evaporation can be calculated.

52. I have carried out this operation for the two stations; from the actual pan figure at Maseru of 2145 mm I get a lake evaporation of 1560 mm, giving a pan factor of 0·73; at Oxbow the pan figure of 1553 mm becomes 1270 mm, with a factor of 0·82. The monthly pan factors shown in Fig. 4 average out at 0·705. I assume that these factors are for the pan at Maseru, where they would result in a lake evaporation of 1510 mm. The factors cannot be applied at Oxbow as the other conditions there are different.

53. It is known that the pan factor varies inversely as the amount of pan evaporation, and in this respect the levels of the factor shown in Fig. 4 puzzle me as they do not seem to bear any relation to the pan figures. In my calculations the factor varies from 0·70 in January, when the evaporation was the highest, to 0·77 in May and June, corresponding to low evaporation. Pan factor is a direct factor of the difference in air and water temperatures. When the air temperature is the higher the factor exceeds 0·70, which is taken to be the appropriate factor for equal temperatures. When

humidity is low, and increased water losses lower the water temperature, the factor falls. The factor also rises with increased elevation; the proportion of advected energy used for evaporation is increased because of the fall in pressure and the effect of temperature difference is reduced if it is negative.

54. It would be helpful, to enable these pan records to be used for further study, if the pan water temperatures as monthly means were available. Could the Author give these figures? The procedure for class A pan operation provides for floating thermometers.

55. I assume that the mean air temperatures and humidities were the true means from the thermohydrograph charts. Diurnal variations of these factors are necessary where observations are limited to maximum and minimum temperatures and to twice daily, wet and dry bulb readings. Humidities are very unstable in the tropical belt, and in higher latitudes temperatures have marked seasonal differences in the time they apply and factors are needed if only limited observations are available.

56. The wind run was recorded at a height of 2 m; to reduce this to the run at the usual class A height of 6 in. above the pan rim (0·56 m), I have used the factor 0·70. Were the anemometers directly adjacent to the pans, and was the immediate surrounding ground free of wind obstructions such as long grass?

57. I notice that some pans were screened and adjustments of 0–20% were made to the unscreened condition. In Ghana, with a pan protected by one inch mesh of $\frac{1}{16}$ in. gauge, a correction of 13% was required.

58. Over the years many engineers have sought an easy way, by means of quasi-empirical formulae, of estimating lake evaporation from the basic factors, air temperature, humidity and wind speed. Joining this band with a formula to give the annual evaporation from a class A pan if there were one at the supposed lake gives

$$E_p = 1050[(1-H)e_s(0{\cdot}42+0{\cdot}0025U_p)]^{0{\cdot}5}$$

where e_s is the saturated water vapour pressure at air temperature in millimetres of mercury, H is the relative humidity expressed as a fraction and U_2 is the daily run of wind at height 2 m in kilometres. E_p will be the annual total pan evaporation in millimetres.

59. The resultant curve is a parabola and fits the pan figure at Oxbow at one end and at the higher extreme the pan evaporation at Boulder Lake. Between these limits this curve may be slightly low on E_p, and perhaps the index should be less than 0·5.

60. Then, to apply a factor to the pan evaporation, this can be found from the equation

$$p = 0{\cdot}90-0{\cdot}000\,085\,E_p$$

This straight line gives 0·78 for Oxbow, 0·72 for Maseru, and at the top end 0·60 at Boulder Lake, which was the calculated figure, and covers other stations with little bias, but on the high side. Probably a more appropriate curve would be a die-away curve, with a unity value of p at zero evaporation and asymptotic at about $p=0{\cdot}30$ at complete evaporation. This would fit Oxbow more satisfactorily.

61. This process appears to me to be as good as any other.

Mr West

Both the Contributors have emphasized the advantages of relative humidity. However, no thermohydrograph records are available, but spot checks of hourly variations of wet and dry bulb temperatures showed that twice daily observations gave a good indication of the daily mean at Maseru. It was also found that, for Maseru and Oxbow, monthly relative humidities calculated from the monthly means of wet and dry bulb temperatures were generally within 2% of monthly means of daily relative humidity.

63. The short-duration rainfall records in Lesotho were insufficient for detailed analysis, but tended to confirm the results of the studies summarized in Fig. 6.

Data such as **Mr Bulman** requests in § 40 will no doubt become available as the number and duration of autographic records increases. No obvious lapse rate for short intense rainfall is apparent from records in Lesotho, but wetter areas seem to experience more frequent, rather than heavier, storms.

64. I agree with Mr Bulman that correlations between flow and effective rainfall are more significant than those between flow and total rainfall. However, in practice losses (and hence effective rainfall) are rarely found directly, but rather by comparison of total rainfall and runoff. The term mean annual flood in Fig. 10 and § 25 does indeed refer to the average of annual peaks. Left bank tributaries were excluded from Fig. 10 because their data did not exhibit an obvious correlation, but in general their peaks were lower than in the rest of the catchment. This is probably due at least partly to thicker and more permeable soil cover.

65. The methods described by **Mr Porter** for estimating pan evaporation and pan factor belong to the large family of empirical formulae for evaporation, based on meteorological parameters, which have been derived in recent years. Many of these have proved useful in the areas for which they were derived, but they may not be applicable elsewhere unless, like the Penman method, they take account of all the important variables, including temperature, vapour pressure, wind, and incoming and outgoing radiation. The pan factor may in certain circumstances vary inversely as evaporation, but the Lesotho winters are cold, dry and sunny, so that the brief hot sun produces proportionately greater heat storage changes in the pan and a lower (more extreme) pan factor. The pan factors in Fig. 4 are for Maseru; Oxbow pan evaporation and pan factors are of lesser significance during winter months, when the pan is covered by ice. The pans were installed on ventilated wooden platforms with short grass surrounds, and anemometers were installed in the same compounds.

66. The danger of extrapolating short records is well recognized in Lesotho, and improvements to the hydrometeorological network form a major part of the effort of the Hydrological Survey. Meanwhile planning of water resources' development has to be based on the data available. The programme for data collection has to take account of the difficult terrain and scarcity of observers, and the aim of the recent work described in the Paper has been primarily to present the data in a form which is useful even where records are scarce.

Reference

12. BULMAN R. B. *Effective rainfall.* Bushby, Carlisle, 1969.