Aspects of hydrology in the province of North Sumatra, Indonesia

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In 1977, the Overseas Development Administration appointed consultants to supply a team of specialists to strengthen and train members of the West Sumatra Design Unit, in the province adjacent to that which was the subject of the Paper. In the period up to 1981, various hydrological studies were undertaken in West Sumatra of a similar nature to those described for North Sumatra. In a separate project, funded by the World Bank, detailed water resource studies were also carried out for a transmigration project of some 38 000 ha overall, around the village of Sungai Dareh in the east of West Sumatra. The results from these studies are compared with those from North Sumatra.

59. The physical geography of West Sumatra is similar to that described for North Sumatra. Three broad landscape units can be recognized: a relatively narrow alluvial coastal plain in the west; the Barisan mountain range inland from this; and the area to the east of the mountains. Much of the province is remote and covered with tropical rain forest, although there are also important areas for crop production on the lower ground. The efficient development of the considerable water resources of the province is essential to improve agricultural production and the overall quality of life for the inhabitants.

60. As in North Sumatra, purely in terms of the number of stations, West Sumatra appears to have a reasonable hydrometric network, but since the climatic parameters not only vary spatially but also display extremes that approach the highest figures to be found anywhere in the world, further effort is required, particularly with regard to the retrieval of data from the network.

61. Historically, a network of daily rain-gauges had been installed during the Dutch colonial period, but this was largely destroyed during the Second World War and is only gradually being re-established and expanded to include autographic rain-gauges and complete agro-meteorological field stations. An inventory of the existing and proposed network was prepared²⁶ and studied in relation to proposed water resource developments. Suggestions were put forward for improving the network and the quality of existing data.²⁷ A detailed statistical analysis was undertaken of the rainfall data for the airport at Padang on the west coast, the provincial capital and site of the best maintained gauge in the region operated by the National Meteorological Service.²⁸ The average annual rainfall over 31 years

was 3935 mm with a standard deviation of 714 mm. October and November are the wettest months at the onset of the north-west monsoon. The maximum daily rainfall in the period from 1911 to May 1980 was 289 mm, with several other falls in excess of 200 mm also recorded at this station, which is only a few metres above sea level. On the west coast with increasing altitude, mean annual rainfall totals initially increase up to about 800 m, but then decrease with a further increase in height.²⁹ To the east of the Barisan range is a relative rain shadow, illustrated by the figures from Sungai Dareh which has a mean annual rainfall of 2933 mm.

62. Despite the apparent abundance of rainfall in Sumatra, much of the rain occurs in intense bursts of short duration and runs off rapidly. Significant periods of drought can therefore occur, especially during the months of June and July when the region is under the influence of the drier south-east monsoon. A statistical frequency analysis of the seven years of annual maximum series from the autographic rain-gauge in Padang can be compared with the values given in Fig. 9 of the Paper. For a return period of once in five years, rainfall intensities of 85, 54 and 27 mm/h were obtained for durations of 1, 2 and 6 h, respectively. These results seem similar to, but slightly higher than, the Medan gauge, which could be attributed to the more westerly location of Padang.

63. There is still a shortage of good-quality flow data in West Sumatra for the reasons outlined in § 19 of the Paper. However, for two sites, short series of annual maximum flows were available and these series were found to be quite well described by a Weibull distribution. Using all the available data, a preliminary attempt was made to relate the once-in-five-year low flow for various rivers to

Table 5. Growth factors for Sungai Dareh and Pemali Comal

Return period, <i>T</i>	Sungai Dareh, growth factor	Pemali-Comal, growth factor
5	1.28	1.17
10	1.47	1.27
25	1.70	1.41
50	1.91	1.51

Fig. 16. Mean monthly Penman evapotranspiration estimates

catchment area and mean annual rainfall. However, the resulting relationship was not sufficiently strong for final design purposes. Further work is needed on low-flow estimation methods, since attempts are being made to double-crop rice and increase the total irrigated area. July is the month when most of the rivers in West Sumatra experience their lowest flows.

64. For the Sungai Dareh project,³⁰ a set of growth factors relating the mean annual flood to floods of other common return periods was obtained for four catchments ranging in area from 344 km² to 4594 km² using a peaks-over-a-threshold analysis. The factors were surprisingly constant but the average values obtained were considerably lower than the values presented in Table 4 of the Paper. A regional analysis of flood peaks in the Pemali-Comal Sub Project area of north central Java³¹ was found to yield an even flatter growth curve than that of the Sungai Dareh area. The results from both areas are presented in Table 5. These suggest that the growth factors for estimating design floods in Table 4 of the Paper may be conservative and emphasizes the need for caution in using such relationships for areas outside that for which they were derived.

65. The Penman evapotranspiration estimates for a short green crop presented in Fig. 10 of the Paper confirm the Authors' use of 3.5 mm/day for preliminary studies of water requirements in the Province.³² The Padang evapotranspiration estimates are consistently higher than the values for Sungai Dareh, reflecting the western coastal position of the former with lower cloud cover and higher wind-speeds. Fig. 16 shows the estimated mean daily Penman evapotranspiration estimates for both Padang and Sungai Dareh for each month. Figs 10 and 16 illustrate the typical lack of annual variation in evaporation rates observable in the humid tropics.

Mr R. B. Bulman, Consultant

The Authors are to be congratulated on their excellent review of the hydrology of North Sumatra. The statement in § 26 that there are distinct relationships between the average of daily maxima and mean annual rainfall is rather difficult to follow. A negative correlation of daily maxima with altitude is to be expected in this climate. If the data in Fig. 8 were separated into areas of similar geographical exposure, would positive correlations of mean annual rainfall with altitude emerge?

67. The constant b in equation (1) can only have a value of 0.205 and not the range indicated if the equation is to be satisfied at 24 h. This type of equation only requires the constant b artificially in order to avoid intensities approaching infinity at very short durations, and there are advantages in replacing them by equations giving the depth of rainfall at short durations. How well would the original data fit an equation of the following type

$$d = 0.73t^{0.10}X(T, 24) \quad (3)$$

where d is the depth of rainfall in duration t .

68. In § 31 it is noted that an error of 5% in the estimate of mean monthly humidity influences the Penman evaporation by 4%. In view of the large diurnal variation there will be an even greater error resulting from use of mean monthly relative humidity rather than mean monthly saturation deficit. Penman's equations are based on saturation deficit, and using the mean monthly estimate of relative humidity is very similar to using the harmonic mean of saturation deficit. Alternative methods of calculating mean saturation deficit are available,³³ but if

DISCUSSION

the basic data are available there are advantages in calculating the saturation deficit directly from all available observations and then taking the mean value.

69. The comparison, in Table 2, of very short-term mean annual run-off values with long-term mean annual rainfall could be misleading. The average duration of the run-off records is only about five years, or less than half the presumed period of the rainfall cycle. The mean annual value of the run-off will depend on which portion of the rainfall cycle the records have come from. The value of Table 2 could be enhanced if the rainfall for the years of run-off records were analysed and a further column added showing the average *excess* catchment rainfall for the years in question. For reasons given in § 70 all mean and average values could be replaced by median values.

70. The confidence expressed in regional growth curves in § 44 may be rather misplaced, especially since they are based on the average value of annual maxima. In § 43 the Authors have noted that rating curves are inadequately defined for high stages. This is quite common experience even in developed countries. The average value of annual maxima itself cannot therefore be as stable as desirable. However, the median value of annual maxima is virtually independent of the accuracy of the higher discharge measurements, and represents a much more stable starting point for the study of discharge-probability relationships in an individual catchment area.

71. Every catchment area is unique and regional curves derived by statistical methods can give no more than a first approximation for a particular catchment. A rigorous analysis of the individual catchment and rainfall regime must follow if there is to be any confidence in the final estimate.

Mr Wild and Mr Hall

We are grateful to Mr Wood and Dr Hall for outlining the hydrology of West Sumatra. It is interesting to note the similarities with North Sumatra and the common problems faced in analysing the available data. As noted in § 62, the

Table 6. Comparison of flood growth

Source	Location	Return period, <i>T</i> years			
		5	10	20	50
North Sumatra Design Unit	North Sumatra	1.6	2.15	2.65	3.3
West Sumatra Design Unit	Sungai Dareh	1.28	1.47	1.65	1.91
Sir Wm Halcrow & Partners ³¹	Pemali-Comal	1.17	1.27	1.38	1.51
Snowy Mountains Engineering Corp ³⁴	Central Java				
Institute of Hydrology ³⁵	Cimanuk, West Java	1.45	1.65	1.95	2.40
Institute of Hydrology ³⁵	Java: (low extreme)	1.11	1.19	1.29	1.39
Institute of Hydrology ³⁵	Java: (averaged regional)	1.22	1.46	1.69	2.08
Institute of Hydrology ³⁵	Java: (high extreme)	1.36	1.89	2.48	3.42

west-coast location of Padang is an important factor which influences average rainfall, rainfall intensities and evapotranspiration estimates. Characteristics at Padang are more akin to those at, for example, Sibolga on the west coast of North Sumatra than for Medan.

73. The comment that 'climatic parameters display extremes that approach the highest figures to be found anywhere in the world' is applicable to rainfall but not to other parameters such as temperature, relative humidity, sunshine duration and wind speed which, as shown in the Paper, are remarkably predictable over large regions and have limited seasonal variations.

74. The Paper explained that the growth factors for estimating design floods presented in Table 4 are conservative. In view of the scarcity of discharge data and the large uncertainties associated with many of the stage-discharge curves at high stages, it was felt prudent for design purposes to adopt conservative factors whilst emphasizing their preliminary nature. For detailed design work, it is certainly recommended that any local data and information on historic flood levels from local inhabitants be taken into account. Major structures where failure would endanger lives would be designed using a more rigorous analysis which might include probable maximum precipitation and flood studies.

75. The growth factors presented in Table 5 for Sungai Dareh in West Sumatra and especially for the Pemali-Comal area of Central Java appear low in relation to both the North Sumatra figures and to studies elsewhere in Indonesia. Table 6 compares the factors with those derived by the Snowy Mountains Engineering Corporation³⁴ for the Cimanuk dam project in West Java and with the results of a recent study by the Institute of Hydrology (IOH), Wallingford, for the whole of Java.³⁵ In this study, data for about 50 catchments in Java were reviewed and analysed. Mean annual floods were determined from either an analysis of the annual maxima series or a peaks-over-threshold model and then related to catchment characteristics using multiple regression techniques. The extreme and averaged regional growth factors are summarized in Table 6. The quoted Pemali-Comal factors are close to the lowest extreme for Java from the IOH studies.

76. Regarding low flows, recent studies in the Province of Central Java have demonstrated the dominant effect which catchment geology has on low flow characteristics.³⁶ Four broad geological classifications can be identified namely, recent volcanics, mixed volcanics, old volcanics and sediments. The very porous recent volcanics have high infiltration rates, groundwater storages and a relatively slow baseflow recession producing a high baseflow component and maintaining good dry period flows. At the other extreme, the old volcanics and sediments (which appear to have comparable run-off characteristics) have small groundwater storages and more rapid baseflow recessions producing lower dry period flows. Data from 13 catchments in Central Java were analysed and monthly reliable flows (i.e. flows which would be exceeded in that month in four out of every five years on average) were expressed as percentages of the average daily flow and the catchments grouped according to the predominant catchment geology. The results were sufficiently consistent to apply to ungauged catchments for determining, at a pre-feasibility level, the monthly reliable flows which are the usual criteria for designing run-of-river irrigation schemes in Indonesia.

77. In reply to Mr Bulman's point about rainfall relationships, a more accurate description of Fig. 8 would be that there are distinct trends between the mean daily maxima and mean annual rainfall. The data used in Fig. 8 are derived from

stations covering a wide range of geographical exposures and altitudes. Where detailed rainfall studies have been carried out in specific locations, the relationships between mean annual rainfall and altitude were ill-defined. Studies in parts of Central Java where the station network is more dense show trends of increasing mean annual rainfall up to 800–1000 m and at higher altitudes for mean annual rainfall to decrease (confirming the observations in West Sumatra). The rates of increase and decrease appear to be influenced by the direction of the slopes and the monsoon air currents but are inadequately defined to assist for example with drawing isohyetal maps.

78. The constants in equation (1) provide the best fit over the range of durations from 0.5 to 24 h. Using b values of 0.28 to 0.34 instead of 0.205, which provides an exact fit at 24 h, leads to errors of less than 0.5% at 24 h and provides a much better fit at shorter durations. For each return period considered, the correlation coefficient exceeds 0.99. The best power curve fit relating rainfall depth, d , and duration, t , is provided by

$$d = 0.64t^{0.14}X(T, 24) \quad (4)$$

where $X(T, 24)$ is the 24 h rainfall total associated with return period T . However, the fit is not as good as the formula suggested in the Paper, having a correlation coefficient of the order of 0.91 to 0.94 over the range of return periods.

79. In reviewing the various methods available for deriving potential evapotranspiration, Penman³⁷ states that e_a is the mean vapour pressure of the atmosphere derived from routine humidity observations and e_s is the saturation vapour pressure at the mean air temperature. The saturation deficit is simply the difference between the two. FAO³⁸ have examined for a range of climates the effects of the manner in which the saturation deficit is computed and conclude that the simpler calculation based on mean temperatures and humidities is preferable.

80. Under normal circumstances, comparisons of mean catchment rainfall and run-off should be based on records for the same period. The problem is that many of the long-term rainfall stations in North Sumatra cover periods prior to the Second World War whereas the run-off records cover recent years. In some catchments the existing rainfall network is sparse and recent data covering the period of run-off record are fragmentary or inconsistent with previous data. Where design studies were carried out, the recent rainfall data were checked for homogeneity and concurrent rainfall and run-off records were analysed.

81. In North Sumatra, many of the river gauging stations' rating curves are inadequately defined at discharges exceeding two or three times the average daily flow, i.e. at discharges lower than the mean annual flood. In these cases, estimates of both the mean and median annual floods would be subject to serious errors. Where the rating curves could be extrapolated satisfactorily on the basis of velocity and area curves then the mean annual floods (Table 3) were estimated by fitting peak-over-threshold models as recommended in the UK *Flood studies report*.³⁹ The periods of record range from five to eight years. Unfortunately, the data are not to hand so it is not possible to give the mean and median values derived from the annual maxima series for comparison.

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