"flooding characteristics are highly regionalized, especially since the difference between flood frequency parameters from region to region is large . . ."

General Formulae for Flood Frequency

by

G. L. Stevens and
Pedro T. Templo*

Introduction

Because measurements are not always available at points on streams where discharges of a given frequency are needed for design, hydrologists have traditionally developed schemes to determine the discharge of ungaged drainage areas in hydrologically similar regions for a range of frequencies. These schemes usually took the form of a peak annual flow frequency analysis of the streamflow measurement records in the region of similarity. Although these traditional solutions have filled a pressing need, which seems to grow more urgent with time, the application of these techniques have not been rigorous and in the last analysis, the results were highly subjective.

From the basic principles of hydraulics and hydrology, we know that the magnitude of the peak flow for a given drainage area and frequency depends to a large extent upon the general meteorologic, physiographic, and antecedent conditions that prevail in the region of similarity. Ideally, the general formulae for determining the flood frequency parameters for the region should reflect these characteristics. In fact, the flood frequency parameters should be directly derivable from these regional characteristics.

In this study, general formulae were derived for the computation of regional flood frequency parameters from quantifications of the regional characteristics mentioned above. These formulae are applicable to any region in the Philippine Archipelago or other geographic locations in which the relevant characteristics

*Professor, Dept. of Engineering Sciences, U.P. College of Engineering

are comparable. But before these general formulae could be derived, it was necessary to determine the frequency parameters for each region in the Archipelago by peak annual flow frequency analysis, so that their relationship to the above-mentioned regional characteristics could be determined.

Regional Peak Annual Flow (PAF) Frequency Analysis

The regional flood frequency parameters were determined by peak annual flow frequency analysis of measured records in each of the political regions in the Philippines. Fortunately, the measured streamflow records of the stations encompassed within each political region proved to be hydrologically similar but with flooding characteristics sufficiently different to be considered very nearly the limit of that similarity. The particular method of analysis utilized by the study was that of the U.S. Geological Survey as set forth in Reference 1 which consisted of the following procedural steps.

1. Record Selection

This step consisted of selecting the stations in each region whose peak annual flow records were suitable for the study and from this selection of stations choosing a long term station for the region. In this study, only records with lengths longer than 5 years were utilized with the long term station being the station with the longest record.

2. Extension of Records

The records of the short term stations were extended to that of the long term station by regressing them against the long term station. In the course of these regressions, the problem of an insignificant correlation coefficient was pervasive, a problem for which the following solutions were devised.

a. Transformation

The PAF records of both the short and long term stations were transformed by taking their logs and these logs were then regressed against each other. Although this modification resulted in an improved correlation coefficient, the insignificance of this coefficient was still pervasive.

b. Non-Parametric Regression

The similarity of basin characteristics that causes drainage areas to have similar flooding characteristics does not require that floods for the same order of magnitude be the result of the same storm, only that the storm characteristics in the long run be similar. Hence, the non-significance of the correlation of peak annual flows for the long and short term station can be explained by the postulation that the storms that generated the peak annual flows at the two stations for a given year were of different orders of magnitude relative to the remainder of the record at these stations.

However, the insignificance of this year by year correlation did not invalidate the assumption of similar storm types and magnitudes within the region of similarity. If in the same years, the storms of the same relative magnitude had been centered over both basins, the peak generated by these basins would have been highly correlated if their physiographic and antecedent condition characteristics were similar. Therefore, if we assume that the regional meteorologic characteristics are relatively uniform, the question is not whether the basins produced comparable floods in the same calendar year but whether they produced comparable floods when storms of relatively equivalent magnitude were centered over them.

In other words, if we assume that storms of equal magnitude occurred throughout the region of similarity but not necessarily in the same year, then the years in which the storm magnitude over the short and long term stations were equivalent should be paired in the regression of one record against the other. If we assume that the larger storm in general produced the larger runoff for the basin over which it was centered, then the PAF magnitude becomes a measure of the storm magnitude and PAF's of the same magnitude should be paired against each other in the regression. With the conversion of the regression from parametric to non-parametric by first ordering both the long and short term station PAF's, the correlation coefficient of regression was significant in all cases.

3. The Median Frequency Factors

The extended record at each station in a given region was then converted to normalized flows (NF's) by dividing the PAF's at that station by the mean PAF at the same station. These NF's at each station were then ordered from largest to smallest and the median NF for each order of magnitude was selected as the regional NF for that order of magnitude. These regional NF's were then fitted with a frequency distribution as the frequency curve for that region so that the NF for any return period and drainage area could be determined. In this study the Log-Pearson Type III as set forth in Reference 2 was used for both the station and regional NF frequency curves. The NF's for selected return periods are given for all regions in Table 1.

4. A Formula for Mean PAF

A formula to obtain the mean PAF for a given drainage area was developed for each region by regressing the log of the mean PAF at each measuring station against the log of its drainage area. Unfortunately, the correlation coefficient of this regression proved to be pervasively insignificant. Therefore, the following methods were devised to obtain a significant correlation, since an insignificant correlation coefficient may mean a spurious regression equation.

a. Non-parametric Correlation

The first solution to the insignificant correlation coefficient was to order the drainage areas and the mean PAF's and then regress the mean PAF's against the drainage areas of the same order. This ordering was justified by reasoning that the lack of correlation before the ordering was due to non-uniform storm magnitudes over the basin during the period of record and that had the larger storms occurred over the larger basins, the larger basins would have produced the larger runoffs. This reasoning conforms to the underlying assumption in this method of PAF regional analysis, i.e. that the regional physiography is relatively uniform. However, it does not account for the increased area over which the storm would have fallen. Hence, it is a conservative assumption. Even so, the resulting correlation coefficient of this non-parametric regression proved to be significant in all cases.

b. Dropping the Outliers

A second method of obtaining a significant correlation coefficient was to drop the point with the largest deviation and test for the significance of the correlation coefficient for the regression without this outlier. If it were still not significant the point in the remaining set of PAF's v.s. DA's with the largest deviation was dropped. This was continued until the correlation of the regression met the criteria set for significance, although it was never necessary to drop more than two points. As above the dropping of the outliers was based on the non-representativeness of the storm magnitudes during the study period as a sample of population of the storm magnitudes for the region with emphasis on the non-representativeness of the record over the outlier basin(s).

5. Tests for Regional Similarity

The similarity of the PAF records in a given region were tested in two ways, the first test utilized the U.S. Geological Survey's homogeniety test as set forth in Reference 1. The second consisted of testing whether the 10 year NF for a given region fell within the 95 percent confidence limits for the 10 year NF's for all the regions. If the NF for a given station within a region failed the test, that station was dropped and the analysis redone without that station.

6. Removing Outliers from Frequency Parameters

From Steps 3 and 4, the frequency parameters for each of the 12 regions of the Philippine Archipelago was developed as shown in Table 1. Because of the well known tendency of the mean unit runoff to decline as the size of the drainage area increases, the unit runoff is listed for both the 1 and the 1000 square kilometer drainage areas with the intent of computing the unit runoff for the intervening areas by a logarithmic interpolation formula. The 1 and 1000 square kilometer drainage areas were the limiting areas used in the study.

Since the flows have not been measured long enough to get a true sample of the PAF population, the PAF records were biased, especially in certain regions, because the rainfall records during the period of streamflow measurement were not statistically representative of the long term rainfall of the region. This bias in the rainfall record is illustrated in Figure 1 in which the difference between the average maximum rainfall for 10 and 24 hours durations becomes unbelievably small for some regions, especially since these depth duration frequency curves normally plot as straight lines.

Also, systematic inaccuracies in the streamflow measurements may have contributed in some regions to the unrepresentativeness of the sample. Even so, the general results of the above regional PAF frequency analyses were statistically satisfactory, since they passed the significance tests.

However, as is usual in regional PAF frequency analyses, certain results were out of the range of credibility due to these biased records. Therefore, to fully establish the credibility of the results from a hydrological standpoint, minimal smoothing was required, i.e. the outlier parameters had to be replaced. This preliminary smoothing was accomplished by comparing the results of each region to the unsmoothed averages for all the regions of the corresponding values. But the rules for this preliminary smoothing were kept clear and simple and their application without exception in order to preserve the objectivity of the study.

This preliminary smoothing consisted of setting an upper and lower limit of values and ratios for each parameter in order to identify the outlier values to be replaced by the limiting value. By using the unsmoothed averages for all regions as a standard of comparison, the results from each region were supported by the records from all the other regions, since these averages included all the statistical advantages of the regional parameters by incorporation and were further smoothed by the effect of compensating errors between regions. In a sense these mean values are averages of all the records in every region of the study.

The preliminary smoothing of the mean unit runoff for 1 square kilometer (MUR1) began with the selection from either the unrearranged (UNR) or the rearranged (R) MUR1 for the region. The criteria for this selection was whether the UNR MUR1 was greater than twice the average of these UNR values for all the regions. If it were not, the UNR value was taken, but if it were larger, the R value was chosen. Using this criteria, only two of the R values were selected. The second test of the MUR1's was whether they were smaller than one half of the average of these unsmoothed UNR values for all the regions. In two regions, both the UNR and R values of this parameter were smaller than half the average. Consequently, the MUR1's for those regions were taken to be one half the unsmoothed UNR average of these values for all the regions.

Again, the preliminary smoothing of the mean unit runoff for 1000 square kilometers (MUR1000) began with the choice between the UNR and R values for this parameter. The criteria for making this choice was whether the ratio of MUR1 to MUR1000 for the UNR values was less than 1.5928 or greater than 3.055, the first value being the average ratio of the R values and the second being the average of the average UNR and R ratios for all the regions. Under this criteria, 3 MUR1000's were taken from the UNR values for this parameter and 1 from the R values. In case both the UNR and R values fell outside this range, the MUR1000 for the region was computed from the smoothed MUR1 by the ratio which it violated. Only 1 MUR1000 was computed from the lower limiting ratio and 7 from the upper. This parameter required more smoothing because of the bias in the long duration maximum-rainfall-depth records as shown in Figure 1. The bias of the record in some regions is indicated by the downward curvature of the line for the longer durations. This curve is normally a straight line.

The criteria for the preliminary smoothing of the normalized flows for the selected return periods were the limiting values of one half and twice the average of the unsmoothed regional values for all the regions. Using this criteria only 1 NF was smoothed.

The results of this preliminary smoothing with respect to the MUR v.s. frequency relationship for both MUR1 and MUR1000 are shown in Table 1.

The General Formulae for Regional Frequency Parameters

1. The Need for Further Smoothing

The preliminary smoothing merely established the credibility of the results, but did not necessarily take full advantage of the support that one regional record can offer another, i.e. the preliminary smoothing did not go as far as possible in removing the record bias. For example, the 100 year NF's of Regions V and VIII differed by 390 percent after preliminary smoothing, although these regions are adjacent to each other and both have an eastern exposure to the Pacific Ocean. Intuitively, such differences between these regional parameters from region to region seem too large, but an objective comparison of regional results must account for the differences in the regional characteristics that control these variations.

An ideal solution would be to develop a numerical relationship between the PAF frequency parameters and the regional characteristics which control them as well as a numerical measure of the relationship between these parameters and characteristics. If this numerical relationship could then be used to smooth these parameters to the degree justified by their correspondence, the support of one set of regional parameters for the other would be maximized and the maximum statistical value would be obtained from the available measurements.

2. Choosing the Regional Characteristics

Obviously, the regional characteristics that control the relationship of mean PAF v.s. drainage area and the regional NF v.s. frequency are the general meteorologic, physiographic, and antecedent condition characteristics of the region. The problems that remain is how to identify and quantify these characteristics.

The meteorologic conditions that control the relationship between mean PAF v.s. the drainage area and the regional NF v.s. frequency is the maximum depth duration frequency curve for the region. Since this curve is usually a straight line on log-log coordinates, the end points of the curve should satisfactorily represent it.

The physiographic conditions that control the relationship of mean PAF v.s. drainage area and the regional NV v.s. frequency are the size of the drainage area, the length and slope of the main stream channel as well as the basin shape. However, a comparison of these characteristics from region to region reveals that they vary over about the same range with the exception of slope, so they are not representative of the differences in characteristics that cause the differences in the parameters. But, it is altogether feasible that one region may be generally steeper than another. Therefore, the slope of the basins in a region are a genúine regional physiographic characteristic which exerts a measure of control over the above relationships.

Since the relationships of the mean PAF v.s. drainage area and regional NF v.s. frequency are both in one sense averages, the average antecedent conditions that prevail during the PAF is the characteristic that is representative of the control of antecedent conditions over these relationships. Since the PAF usually occurs during the month of maximum rainfall, it is the antecedent conditions prevailing during this month which are most representative of the control of this characteristic over these relationships.

3. Choosing the Method

A method is sought that will establish a numerical relationship between the regional PAF frequency parameters and characteristics as well as provide a numerical measure of the degree of correspondence. Since regression analysis with its correlation coefficient met these criterion, it was chosen as the method to be used in this study. Although there would be only 13 observations for the culvert and bridge site regression and 26 for the all site regression, these observations are averages and are representative of the 1556 sites and 250 station years of PAF records utilized in this study, not to mention the station years of record backing up the regional characteristics.

4. Application of the Method Chosen

The equations for computing the frequency parameters for a region were obtained by regressing the given "measured" frequency parameters for all the regions against the corresponding regional characteristics for the region. The following regional characteristics were used to quantify the meteorologic, physiographic and antecedent conditions of the region and their values are shown in Table 1.

- * Meteorologic Characteristics
  - – Average Maximum 24 hours Rainfall for given RP
  - – Average Maximum 5 minute Rainfall for given RP

* Physiographic Characteristics
  – Median Stream Channel Slope
  – Range of Stream Channel Slopes
* Antecedent Conditions
  – Normal for Maximum Month of Rainfall
  – Days of Rain for Maximum Month of Rainfall

The frequency parameters for which equations were derived consisted of the following as shown in Table 2.

* Mean Unit Runoff for 1 Square Kilometer
* Mean Unit Runoff for 1000 Square Kilometers
* Regional NF for 5 Year Return Period
* Regional NF for 10 Year Return Period
* Regional NF for 15 Year Return Period
* Regional NF for 25 Year Return Period
* Regional NF for 50 Year Return Period
* Regional NF for 100 Year Return Period
* Product of MUR1 and 100 Year NF
* Product of MUR1000 and 100 Year NF

The equations for these regional frequency parameters are shown in Tables 3, 4, and 5 for culvert, bridge and all site respectively. Table 6 summarizes the order of importance of the regional characteristics in the derivation of each frequency parameter.

5. Analysis of Results

The final conclusion, as to whether the regional characteristics are related to the frequency parameters or to what degree they are related to them, must finally rest upon the coefficient of correlation (COF) of the regression between these regional characteristics and the corresponding MUR's for a given return period. This is because the MUR's for a given frequency are the product of an MUR and an NF of the given frequency, i.e. if either the MUR or the NF is unrelated to the regional characteristics, then their product will be unrelated to them. In this study, the COF between 100 year MUR1 and these characteristics ranged from 92 to 94 percent for the culverts, bridges and all drainage sites; and 94 to 97 percent for the culverts, bridges and all drainage sites; and 94 to 97 percent for the 100 year MUR1000 as shown in Tables 3, 4, and 5.

Furthermore, the quotient of the standard error and the mean of the 100 year MUR1 regression varied from 21 to 25 percent for the three site classifications; and for the MUR1000 for the same return period the variation was from 16 to 23 percent. In this respect it would be well to recall that the correlation coefficient is not an absolute measure of the goodness of fit, but a measure of the improvement of a line estimate of the dependent variable over a point estimate, i.e. the mean. For example, if every observation of the dependent variable were exactly the same, the COF of the regression would be zero but the computed value from the regression equation would be without error, i.e. the standard error would be zero. Since the values used in these regressions were in one sense averages of a great number of other measurements, the standard statistical tests such as for the significance of the COF is not directly applicable, although the correlations are obviously significant. Hence, we are forced to conclude that there is a high degree of relationship between the regional frequency parameters and the regional characteristics shown in Table 1.

From Tables 3, 4, and 5, we see that the COF for the NF's of the three site classifications range from 75 to 99 percent with the COF increasing with the return period. For example, the COF for the 10 and 15 year return periods were 91 and 95 percent respectively for the three types, but for the 25 year return period, it was 97 percent and for the 50 year return period, it was 98 to 99 percent. While the COF of the NF's v.s. regional characteristics for the 5 year return period ranged from 75 to 78 percent over the three site classifications, the COF was depressed because of the relative lack of variation of the 5 year NF's from region to region. For example, the standard error is less than 8 percent of the mean value for all three types of drainage site. This of course is the explanation for increase in the COF from the lower to the higher return periods, i.e. the variation of the NF's from region to region was obviously greater as reflected in their standard deviations.

The COF of MUR1 for all three site classifications ranged from 59 to 75 percent. Again, this is due to the relative lack of variation in these values from region to region, since the standard error divided by the mean ranges from only 20 to 24 percent. The COF for the MUR1000 regression shows quite a bit of improvement varying from 80 to 82 percent with the ratio of the standard error to the mean being 18 percent for all three types of sites.

From Table 6, we see that as expected, the maximum 5 minute rainfall is the most important regional characteristic in determining MUR1, while the maximum 24 hour rainfall is the dominant characteristic for determining MUR1000. Without exception, the days of rain during the month of maximum rainfall is the most important characteristic for determining the regional NF's for each of the selected frequencies studied. For the 100 year MUR's the days of rain alternated with the normal rainfall for the maximum month as the most important characteristic.

With regard to the classification of characteristics under the headings of meteorology (R), physiography (S), and antecedent conditions (A), the order of relative importance as measured by the order of selection in the case of all drainage sites is not only representative of the other types of sites but is definitive. For both MUR1 and MUR1000, the order of selection was RAS, but for all the remaining regional frequency parameters, the order was ARS. This is confirmed by experience in flood hydrology, especially in flood forecasting. In fact, any other conclusion would be unacceptable to a hydrologist with extensive experience in flood forecasting.

6. The Smoothed Frequency Parameters

Tables 7, 8, and 9 show the smoothed regional frequency parameters as computed from the regression equations in Tables 3, 4, and 5. It should also be noted that in most cases, the change in the parameter is toward the mean for all the regions. However, in rare cases, correspondence with regional characteristics requires a more extreme value than was obtained by the PAF frequency analysis of measured flows.

Conclusions

The high correlation between regional characteristics and regional frequency uncovered by this study, lead to the following conclusions:

1. Regionality of Frequency Parameters

Since the regional characteristics that would logically control the regional flood frequency parameters correlate well with them, this high degree of relationship tends to confirm the logic that flooding characteristics are highly regionalized, especially since the difference between these flood frequency parameters from region to region is large.

2. Reliability

The regional flood frequency parameters computed from these formulae are more reliable than those derived from the original frequency study for the region. This is because the formulae tend to remove the effect of record bias and systematic inaccuracy in measurement. In other words, the frequency parameters as smoothed by their relationship to the regional characteristics that control them are more representative of the long term flooding characteristics of a given region.

3. Validation of Measurements and Methodology

The logical presumption, that the magnitude of the regional PAF frequency parameters is a direct consequence of the prevailing meteorologic, physiographic, and antecedent condition characteristics, is very strong. If we consider that it needs no proof, then the high degree of correlation between the frequency parameters and their controlling characteristics becomes a validation of the measurement of both the PAF's and the controlling characteristics as well as the method used in the regional PAF frequency analysis. In other words, the high degree of correspondence is evidence of the accuracy and objectivity of the analysis.

4. A Family of Regional Frequency Curves

Although the frequency parameters computed directly from the derived formulae can be used to construct a regional NF curve for the selected frequencies of this study, an even more reliable curve for all frequencies can be constructed by fitting the six points obtainable from these formulae with a variety of frequency distributions by a variety of fitting techniques. Although the six points would not be enough for such a fit if they were merely measurements, they will suffice in this case since they are supported by all the other records utilized in this study and in a sense are averages of the supporting data.

The above NF frequency curve can be converted into a family of PAF frequency curves by multiplying NF for selected frequencies from this curve by the mean PAF for a given drainage area and plotting that PAF against the drainage area. The formula for the mean PAF for a given drainage area in the region of similarity can be derived from the MUR1 and the MUR1000 for the region, since two points determine a line. However, the relationship is linear only if the logs of the mean PAF's ($\bar{Q}_p$ = MURxDA) are taken. In that case, the equation would take the following form which is representative of the relationship between these characteristics.

$$\bar{Q}_p = KA^D$$

Where A is the drainage area and K and D are constants.

5. A Comparison of Families

While the family of curves constructed from these formulae may not match the family derived from a conventional basin or regional frequency analysis, they nevertheless have certain advantages over them. For example, the family derived from the formulae have removed the effect of record bias and systematic inaccuracy of measurement to a large degree as well as extended the available sample of records for the basin or region by the support derived from relating them to other records. Experience has shown that the analysis of regional as well as basin PAF records can lead to unbelievable results because of a lack of smoothing control. This smoothing is supplied by the restraining relationships represented by these formulae.

6. Transposition of Results

There is no reason to believe that these general formulae for flood frequency parameters cannot be utilized in other geographical locations with regional characteristics within the range of values used to derive these parameters, for example regions in Southern Asia and the South Pacific Islands. However, where sufficient information is available to derive and properly smooth the PAF frequency parameters by the direct application of measured local data, this of course is to be preferred. Even so, it would be interesting to test the degree of relationship that would remain after the inclusion of parameters and characteristics from these comparable regions from other geographic locations.

TABLE 1

REGIONAL FREQUENCY PARAMETERS FOR REGIONS IN THE PHILIPPINE ARCHIPELAGO

REGION	No. of STA	Exp. to Ocean	Unrearrange mean unit RO $m^3/sec/km^2$		Rearranges mean unit R-O $m^3/sec/km^2$		PAF mean unit RO $m^3/sec/km^2$		Normalizes with Outliers Removes Regional Peak Annual Flows for Selected Frequencies						MURO No. 100 yr FF	
			1 km^2	1000km^2	1km^2	1000km^2	1km^2	1000km^2	5 yr.	10 yr.	15 yr.	25 yr.	50 yr.	100 yr.	1km^2	1000km^2
I	13	W	2.135	2.056	1.507	2.242	2.135	1.341	1.8348	2.5034	2.9324	3.5193	4.4081	5.4167	11.565	7.264
II	19	E	3.540	0.830	0.194	1.075	3.540	1.159	1.4312	1.5894	1.6765	1.7739	1.8892	1.9891	7.041	.3054
III	39	W	2.587	1.484	1.731	1.753	2.587	1.484	1.5152	1.8171	1.9869	2.1970	2.4785	2.7586	7.1365	4.0938
IV	37	E, W	2.785	1.090	1.928	1.490	2.785	1.090	1.7782	2.1048	2.2584	2.4220	2.6012	2.7420	7.6365	2.9888
V	38	E	9.180	0.326	4.349	.624	4.349	1.423	1.4739	1.6891	1.7975	1.9206	2.0686	2.1993	9.5648	3.1291
VI	22	W	3.891	0.657	1.235	.935	3.891	1.274	1.3866	1.5507	1.6291	1.7147	1.8126	1.8942	7.3703	2.4132
VII	12	W	1.852	0.320	0.766	.635	1.852	.635	1.6285	1.9110	2.0594	2.2331	2.4503	2.6503	4.9084	1.6829
VIII	15	E	3.346	1.247	2.549	1.147	3.346	1.247	1.5575	2.2569	2.8214	3.7374	5.4806	7.3960	24.7470	9.223
IX	13	W	2.820	0.201	0.855	.614	2.820	.923	1.8587	2.5263	2.9435	3.5016	4.3219	5.2213	14.7241	4.8192
X	13	E	6.810	0.406	3.357	.501	3.357	1.099	2.0539	2.9210	3.4797	4.2433	5.3944	6.6891	22.4553	7.3513
XI	12	E	1.103	0.127	0.211	.553	[21] 1.6967	.555	1.5518	1.8015	1.9307	2.0802	2.2646	2.4318	4.1260	1.3496
XII	16	W	0.671	0.266	0.268	.349	[21] 1.6967	.555	1.4134	1.6366	1.7614	1.9155	2.1215	2.3265	3.9474	1.2912
AVG.	20.75	–	3.3933	0.751	1.582	.9932	2.7621	1.0323	1.6225	2.0168	2.2566	2.5762	3.0571	[3] 3.5666	10.061	3.8534

4.5184 3.055 1.5928

4

1 Twice Per Mean (Value 8.0571) 3

2 Half Per Mean 4

TABLE 2

REGIONAL CHARACTERISTICS FOR THE PHILIPPINE ARCHIPELAGO

Region	mean max, rainfall				Channel Slope				Antecedent Conditions For maximum Floods			No. of Drainage		
	25 yr.		50 yr.		Culvert		Bringe		Maximum		Representative	Sites		
	return	rain	return	rain	drainage	Area	drainage	area	month of	rain	station			
	24th	5 min.	24th	5 min.	mean	range	mean	range	normal Days/	rain	For region	culv.	Br.	All
I	576	21.4	660	23.6	.0039	.1653	.0050	.2775	704.3	22	VIGAN APARRI	22	18	40
II	410	27.0	474	30.6	.0240	.2025	.0051	.0268	280.7	15	TUGUEGARAO	19	5	24
III	368	24.0	420	26.7	.0140	.3205	.0073	.1027	236.5	19	AURORA	43	15	58
IV	400	22.1	461	24.4	.0312	.3562	.02440	.0952	272.3	18	CALAPAN	145	35	180
V	400	25.4	455	28.8	.0480	.3761	.0098	.0723	239.1	16	MASBATE	100	34	134
VI	271	18.8	312	20.6	.0219	.4490	.0051	0191	176.4	15	DUMAGUETE	97	29	126
VIIR	212	18.5	244	20.1	.0150	.1699	.01830	.0340	204.2	19	TAGBILARAN	111	16	127
VIIY	212	18.5	244	20.1	.0396	.1852	.0190	.0740	208.7	18	CEBU	164	55	219
VIII	331	20.4	377	22.0	.0680	.3418	.0198	.2136	670.0	26	BOROGAN	42	35	77
IX	196	18.0	223	19.7	.0300	.2249	.0114	.0825	343.8	23	MALAYBALAY	136	79	215
X	328	19.7	372	22.0	.0540	.3253	.0254	.2359	607.3	26	SURIGAO	101	50	151

TABLE 3
CULVERT DRAINAGE AREAS REGRESSION EQUATION FOR REGIONAL PAF FREQUENCY PARAMETERS

Regional Frequency Parameter	Secondary Regression DE – Transformers				Primary Regression Log – Log Transformation						
	Const Term	Yc CF	STD Gm	TRNS Com CF	Const TGM	R_{24}(25yr.)	R_5(25yr.) CF	Sm CF	Sr CF	Rn CF	Dr CF
MUr_1	–.336822	1.1	.562405	.751479	–1.527970	–.02899	1.30253	1.21577	1.42523	–.05313	.48747
MU_{r1000}	.076447	.931226	.186321	.817946	–1.718400	.87872	.29361	.59496	.39096	–.08613	.20463
NF_5	.023997	.986739	.121181	.782832	.027264	.03307	–.11653	–.82317	–.06634	.00407	.39473
NF_{10}	.081721	.960397	.165231	.913311	–.562797	.09490	–.13300	–.27367	–.04650	.02297	.85509
NF_{15}	.163276	.926318	.179109	.948886	–.873737	.06240	–.15043	–.16829	.01901	.08011	1.13194
NF_{25}	.194876	.920125	.192535	.971862	–1.226350	.971862	–.18437	.19610	.06855	.12878	1.48529
NF_{50}	.251136	.908329	.244076	.981768	–1.854530	.02656	–.18356	.99960	.13472	.19687	1.96009
NF_{100}	.292565	.903550	.362882	.980157	–2.357630	.02001	–.19674	1.51219	.15538	.25644	2.36564
Mur_1*NF_{100}	.619385	.947973	2.136840	.944498	–3.454950	–.33696	.70981	.33851	1.62398	1.87469	–.60881
$Mur_{1000}*NF_{100}$	.339657	.910992	.632836	.967304	–4.276170	–.29560	.73909	–2.64461	1.42465	2.15535	.60388

TABLE 4
Brings Drainage Areas
Regression Equation
REGIONAL PAF FREQUENCY PARAMETER

Regional Frequency Parameters	Secondary Regression DE – Transformers				Primary Regression Log – Log Transformations						
	Const	Yc	STD	TRNS	Const	R_{24}(50yr.)	R_5(50yr.)	Sm	Sr	Rn	Dr
	Term	CF	ENR	Con CF	TERMS	CF	CF	CF	CF	CF	CF
Mur_1	.006351	1.023160	.688054	.590374	−1.605490	.11254	1.28968	2.11720	−.36903	.00973	.35383
Mur_{1000}	.121034	.887995	.195930	.796253	−1.775590	.88869	.22399	−4.54781	−.21233	.01061	.20330
NF_5	.116135	.929602	.122463	.772940	−.030915	.04175	−.04197	2.10175	.03502	−.03336	.39041
NF_{10}	.128721	.936617	.167988	.910251	−.440311	.04375	−.10882	.31167	.17641	−.02005	.85509
NF_{15}	.126413	.943461	.182810	.946692	−.739150	.04193	−.12209	−.94132	.23657	.00328	1.12194
NF_{25}	.112145	.954618	.189617	.973001	−1.269120	.04734	−.15384	−2.38439	.02399	.12380	1.48613
NF_{50}	.057760	.978146	.206106	.986932	−1.781640	.06247	−.24886	−4.1096	.01006	.186939	1.96828
FF_{100}	−.006713	.999600	.290242	.987352	−2.216700	.06414	−.31506	−6.45850	.04733	.24049	2.38112
$MUr_1 * NF_{100}$	−1.565780	1.220010	2.491180	.923751	−4.082600	.04379	1.27982	−3.71880	−.22376	.29379	2.58620
$MUr_{100}NF_{100}$ NF_{100}	.288211	.928057	.791766	.948796	−4.601520	.06887	.66093	.70918	−.51434	2.17189	.46067

TABLE 5
ALL DRAINAGE AREAS
REGRESSION EQUATION
FOR
REGIONAL PAF FREQUENCY PARAMETER

Regional Frequency Parameter	Secondary Equations DE – Transformers				Primary Regression Log – Log Transformation						
	Const	Yc	STD	TRNS	Const	R_{24}(50yr.)	R_5(50yr.)	Sm	Sr	Rn	Dr
	Term	CF	ERC	Com CF	Terms	CF	CF	CF	CF	CF	CF
Mur_1	−.068258	1.051280	.684248	.596430	−1.308450	.02391	1.28968	.51366	.31726	−.08556	.35383
MUr_{100}	.099866	.908753	.184771	.798958	−1.697960	.89277	.29514	.09772	.06981	−.10626	.20421
NF_5	−.038857	1.025970	.127896	.751573	−.045767	.05584	−.07428	−.26744	−.01123	.00407	.39257
NF_{10}	.078656	.962150	.169943	.908043	−.584409	.08771	−.10720	−.14983	.00509	.02207	.85504
NF_{15}	.164594	.925798	.181567	.947434	−.885115	.05853	−.13246	−.17803	.01219	.08011	1.13194
NF_{25}	.179882	.926408	.194537	.971564	−1.315250	.03566	−.10640	−.07397	.01106	.12392	1.48611
NF_{50}	.185461	.931332	.227859	.984129	−1.855820	.00863	−.12390	.07266	.04342	.18639	1.96828
NF_{100}	.181683	.937704	.332993	.983318	−2.341630	.00410	−.14614	.28432	.02252	.24049	2.38112
MUr_1* NF_{100}	−.746800	1.109980	2.126310	.945059	−4.02980	−.09150	1.93393	.12193	.34183	.26813	2.58620
MUr_{1000}* NF100	.597607	.829713	.864157	.938417	−4.166490	−.08728	.52699	−2.34143	.33912	2.16362	.46029

TABLE 6

REGIONAL FREQUENCY PARAMETERS IS REGIONAL BASIN CHARACTERISTIC RELATIVE CORRESPONDENCE ORDER OF SELECTION

PAF Frequency Parameter	Culvert Drainage Ar. Order or Selection						Bringe Drainage Areas Order or Selection						All Drainage Areas Order or Selection						Order or Selections By Chracteristic								
	Max Rain		Channel Slope		Ante-cedent condi-tions		Max Rain		Channel Slope		Ant-cedent condi-tions		Max Rain		Channel Slope		Ante-cedent condi-tions		DA'S			DA'S			ALL DA'S		
																			1	2	3	1	2	3	1	2	3
	6	7	8	9	10	11	6	7	8	9	10	11	6	7	8	9	10	11									
MUR 1	6	1	4	2	5	3	5	1	4	3	6	2	6	1	5	3	4	2	R	S	A	R	A	S	R	A	S
MUR 100	1	4	6	3	5	2	1	4	3	5	6	2	1	3	6	5	4	2	R	A	S	R	A	S	R	A	S
NF 5	4	3	2	5	6	1	4	3	2	6	5	1	3	2	4	65	5	1	A	S	R	A	S	R	A	R	S
NF 10	3	2	4	6	5	1	4	3	6	2	5	1	3	2	5	6	4	1	A	R	S	A	S	R	A	R	S
NF 15	4	3	5	6	2	1	5	3	4	2	6	1	4	3	5	6	2	1	A	R	S	A	S	R	A	R	S
NF 25	5	3	6	4	2	1	5	3	4	6	2	1	4	3	6	5	2	1	A	R	S	A	R	S	A	R	S
NF 50	6	4	3	5	2	1	5	4	3	6	2	1	5	3	6	4	2	1	A	S	R	A	S	R	A	R	S
NF 100	6	4	3	5	2	1	5	4	3	6	2	1	6	3	4	5	2	1	A	S	R	A	S	R	A	R	S
MUR 1 * NF100	4	5	6	2	1	3	6	2	4	5	3	1	5	2	6	4	3	1	A	S	R	A	S	A	A	R	S
MUR 100XNF100	6	4	5	2	1	3	5	3	6	4	1	7	6	3	5	4	1	2	A	S	R	A	R	S	A	R	S

LEGEND:

A – Antecedent Conditions
R – Maximum Rainfall Depths

TABLE 7
Smoothed Regional Frequency Parameters for Regions in the Philippine Archipelago Culvert Series

Region	No. STA	Exp. to Ocean	Smoothed mean unit RUNOFF m3/sec/km2		Normalized and Smoothed Regional Peak Annual Flows For Selected Frequencies						Smoothed 100 years unit RUNOFF m3/sec/km2	
			1km2	1000km2	5yr.	10yr.	15yr.	25yr.	50yr.	100yr.	1km2	1000km2
I	13	W	2.303960	1.378800	1.836460	2.428620	2.782720	3.218680	3.903150	4.634980	15.717400	7.731180
II	19	E	2.956560	1.222320	1.457420	1.629340	1.692230	1.728280	1.805000	1.876150	7.032540	2.910680
III	39	W	3.438670	1.240070	1.644050	2.021230	2.220860	2.444840	2.768220	3.075760	7.573200	3.082640
IV	37	E, W	3.238870	1.281040	1.589820	1.948230	2.134500	2.521720	2.917180	3.287140	7.649800	3.371510
V	38	E	3.877020	1.345110	1.448830	1.706620	1.819950	1.930720	2.123890	2.280090	7.807680	2.821500
VI	22	W	2.733380	.956915	1.485600	1.638340	1.724460	1.792460	1.858630	1.917060	5.480500	1.961430
VII	12	W	1.89292	.704462	1.652075	1.980780	2.16838	2.40248	2.683365	2.970895	5.076765	1.892000
VIII	15	E	3.523930	1.178250	1.796800	2.624880	3.202110	4.052990	5.565790	7.269670	24.627400	8.741920
IX	13	W	2.230520	.690665	1.802370	2.376010	2.777430	3.330630	4.114760	4.960280	9.892600	4.000010
X	13	E	3.227690	1.140770	1.833050	2.645110	3.210450	4.033810	5.457770	7.045770	21.051400	1.918090
XI	12	E	2.549440	.967349	1.493730	1.658180	1.757360	1.838370	1.924560	2.001670	6.690590	2.533450
XII	16	W	2.041520	.609806	1.399920	1.580670	1.677470	1.792250	1.942120	2.074860	5.453910	1.738480
	20.75	–	2.76210	1.032310	1.622480	2.016830	3.256640	2.576130	3.057060	3.566550	10.010000	3.891920

TABLE 8
Smoothed Regional Frequency Parameters for Region in the Philippine Archipelago Bridge Sizes

Region	No. Sta.	Exp. to Ocean	Smoothed mean Unit RUNOFF M^3/sec/km^2		Normalized and Smoothed Regional Peak Annual Flows For Selected Frequencies						Smoothed 100 years Unit RUNOFF m^3/sec/km^2	
			1-km2	1000km2	5 yr.	10 yr.	15 yr.	25 yr.	50 yr.	100 yr.	1-km2	1000km2
I	13	W	2.867610	1.555660	1.702530	2.362530	2.813150	3.422290	4.418960	5.579960	16.684100	8.277300
II	19	E	3.660530	1.350210	1.437360	1.585390	1.666410	1.782300	1.834640	1.881550	7.288000	3.457680
III	39	W	3.294140	1.242470	1.61440	2.010200	2.249140	2.519120	2.903750	3.295850	11.091600	2.774910
IV	37	E,W	3.120260	1.135180	1.660430	1.949740	2.101010	2.278320	2.505570	2.676730	8.053060	3.114540
V	38	E	3.476170	1.262930	1.509490	1.714230	1.823100	1.932980	2.031910	2.117780	7.563340	2.789910
VI	22	W	2.238170	.948198	1.461550	1.643360	1.722630	1.798740	1.877790	1.942700	3.697750	1.531910
VII	12	W	2.329535	.740811	1.64564	1.987300	2.167395	2.381085	2.690185	2.957266	6.47886	2.007475
VIII	15	E	2.900550	1.070750	1.865230	2.652810	3.199100	4.029510	5.414950	6.990690	21.809000	8.290740
IX	13	W	2.398040	.769029	1.738400	2.361410	2.766900	3.379580	4.330120	5.366190	12.930000	3.843010
X	13	E	2.932060	1.010460	1.900050	2.671340	3.193450	5.215490	6.610060	6.610060	20.66040	7.422110
XI	12	E	2.087090	.701662	1.487700	1.677780	1.758060	1.822030	1.903870	1.965210	3.413800	2.002030
XII	16	W	2.173750	.691825	1.424050	1.615470	1.708570	1.822890	1.924190	2.023750	3.981970	2.075210
	20.75	–	2.762110	1.032310	1.622480	2.016830	2.256640	2.576290	3.057060	3.566550	10.010100	3.814950

TABLE 9
Smoothed Regional Frequency Parameters
Regions in the Philippine Archipelago
All Drainage Sizes

Region	No. STA	Exp. to Ocean	Smoothed mean Unit RUNOFF $m^3/sec/km^2$		Normalized and Smoothed Regional Peak Annual Flows For Selected Frequencies						Smoothed 100 years Unit RUNOFF $m^3/sec/km^2$	
			1km2	1000km2	5yr.	10yr.	15yr.	25yr.	50yr.	100yr.	1km2	1000km2
I	13	W	2.926935	1.47188	1.780855	2.39300	2.780530	3.30636	4.12082	4.998912	15.384400	8.61836
II	19	E	3.50467	1.28875	1.451975	1.622840	1.694615	1.78067	1.84085	1.899105	6.88727	3.191025
III	39	W	3.38315	1.24350	1.637550	2.01944	2.218225	2.51359	2.881600	3.230785	9.623555	2.788945
IV	37	E, W	3.01042	1.250675	1.60278	1.952185	2.1292	2.360645	2.66276	2.95163	8.547269	3.042275
V	38	E	3.530895	1.204605	1.497125	1.722725	1.81924	1.94741	2.07611	2.190985	7.691010	2.707725
VI	22	W	2.301955	.906697	1.48441	1.645815	1.717645	1.77489	1.83087	1.871519	3.893885	1.759730
VII	72	W	2.29613	.771272	1.614932	1.965282	2.168300	2.413235	2.750278	3.072752	6.646575	1.1403600
VIII	15	E	2.95313	1.10104	1.85264	2.65405	3.212855	4.03598	5.44807	7.064810	22.426800	8.00819
IX	13	W	2.37946	.72319	1.682860	2.364635	2.77545	3.294725	4.207895	5.13334	12.39895	3.94966
X	13	E	2.96133	1.099015	1.859165	2.64979	3.201905	4.013285	5.40000	6.977245	22.119	7.34272
XI	12	E	2.151605	.898422	1.48821	1.664275	1.753140	1.82142	1.90008	1.96084	3.819510	2.2583200
XII	16	W	2.216235	.609686	1.436585	1.598075	1.696900	1.78239	1.87215	1.950315	4.053635	2.147615
	20.75	------	2.762110	1.032310	1.622480	2.016830	2.256640	2.576210	3.057060	3.566550	10.010100	3.853430

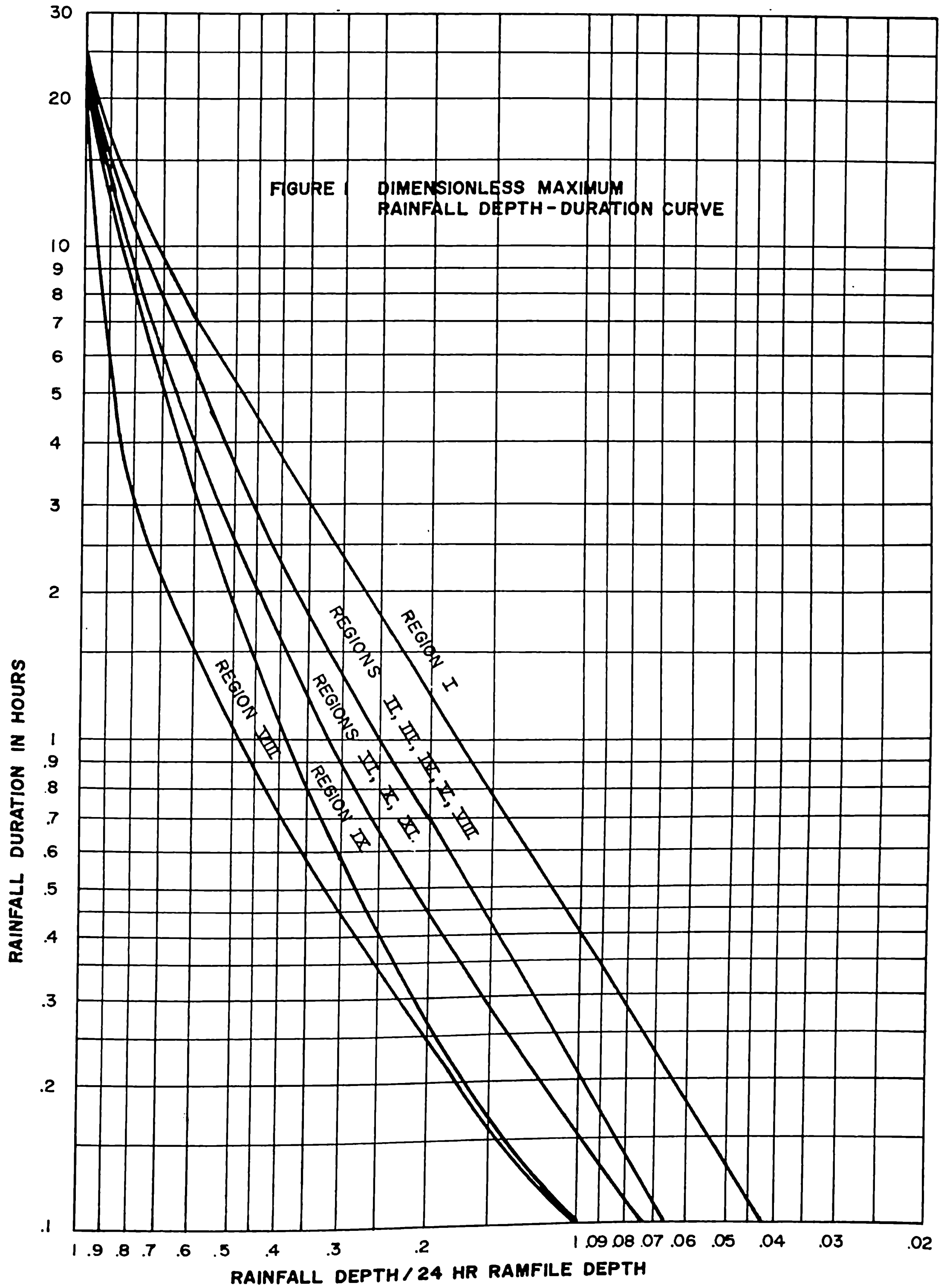
FIGURE I DIMENSIONLESS MAXIMUM
RAINFALL DEPTH-DURATION CURVE
RAINFALL DURATION IN HOURS
30
20
10
9
8
7
6
5
4
3
2
1
.9
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.7
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REGION I
REGIONS II, III, IV, V, VII
REGIONS VI, X, XI
REGION IX
REGION VIII
1 .9 .8 .7 .6 .5 .4 .3 .2 .1 .09 .08 .07 .06 .05 .04 .03 .02
RAINFALL DEPTH/24 HR RAMFILE DEPTH

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