A METHODOLOGY FOR ESTIMATING THE REGIONAL FLOOD FREQUENCIES FOR NORTHEASTERN THAILAND

By

PIROTE KRIENGSIRI

Bachelor of Engineering
Kasetsart University
Bangkok, Thailand
1969

Master of Science
University of Missouri at Rolla
Rolla, Missouri
1971

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Thesis Approved:

Richard N. DeVries
Thesis Adviser

Don F Kincannon

A. F. Gaudy Jr.

Douglas C. Kent

David F. Hicks

Norman N. Durham
Dean of the Graduate College

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GLOSSARY AND LIST OF SYMBOLS

Analysis of Variances (ANOVA) - a statistical technique in which variances of subset of data are compared with the variance of the whole set and with each other to test the hypotheses

ANRAIN - mean annual precipitation for the drainage basin

B_o, b_o - the intercept of regression equation (centimeters)

B_i, b_i - the multiple regression coefficient of the dependent variable Y on the independent variable X_i

C - covariance function

Coefficient of skewness (G) - a numerical measure or index of the lack of symmetry in the frequency distribution

Correlation - association among sets of data having some mutual linear relation, not necessarily cause and effect

Coefficient of Determination (R^2) - a natural measure of the effect of independent variable in reducing the variation in dependent variable of regression analysis

Coefficient of Multiple Correlation (R) - see correlation or the square root of R^2

Degree of Freedom (DF) - the number of independent comparisons which can be made between members of sample

DA - drainage area, square kilometers

e_i - residual, observed error; the difference between observed value and fitted value

ε_i - true error in the regression model can be assumed to be independent normal random variables, with mean and constant variance, σ^2

EL - mean drainage area elevation, meters above sea level

EVAP - mean annual evaporation for each drainage basin (in centimeters)

E - expected value--the expected value of a function of variate value is its mean value in repeated sample

F - name of variance ratio test

f - true error of regression transform in weighted least square method

I - identity matrix

K - Pearson Type III coordinates expressed in number of standard deviation from the mean for various recurrence intervals or percent chances

Level of Significances (α) - the probability of rejecting a hypothesis when it is in fact true. At a "10 percent" level of significance, the probability is 1/10

m - number of independent variable

Mean Square Error - the residual or error sum of squares divided by the number of degrees of freedom on which the sum is based. It provides an estimator of the residual or error variances

Mean Square Regression - the sum of squares for regression divided by its degrees of freedom n - number of observation; in this research, the number of drainage basins

P - a unique non-singular matrix used in the weighted least squares method

p - number of observations of P

Q - coefficient of regression transformation in weighted least squares

Q_T - annual flood peak in return period of T years, m^3/sec

Recurrence Interval (T) - average time interval between actual occurrences of a hydrological event of a given or greater magnitude; 2) in an annual flood series, the average interval in which a flood of a given size recurs as an annual maximum; 3) in a partial duration series, the average interval between floods of a given size, regardless of their relationship to the year or any other period of time. This distinction holds even though for large flood recurrence, intervals are nearly the same as both scales

Return Period - the same as recurrence interval

Sum of Square Total (SSTOT) - the measure of total variation

Sum of Square Regression (SSR) - the measure of the variable of the Y associated with regression line

Standard Deviation (S, σ) - a measure of the dispersion or precision of a series of statistical values such as precipitation, stream flow, etc. It is the square root of the sum of squares of the deviations from the arithmetic mean divided by the number of values or events in the series. It is now standard practice in statistics to divide by the number of values minus one in order to obtain an unbiased estimate of the standard deviation from sample data

SS - surface storage of drainage area, measured by percent

t - a test based on the student's distribution

Variance (S^2, σ^2) - a measure of the amount of spread or dispersion of a set of values around their mean, equal to the square of the standard deviation

V - variance function

W_T - the variance of Q_T used in weighted least squares methods

X - independent variable in multiple regression

Y - dependent variable in multiple regression

$\hat{Y}$ - predicted value from regression model

Z - transform value of Y in weighted least squares

CHAPTER I

INTRODUCTION

Northeastern Thailand contains one-third of the area of Thailand, and comprises fifteen provinces. Its total area is about 155,000 square kilometers (63,000 square miles)(see Figure 1)(1).

The land area of this zone forms a large plateau which dips toward the east. It is enclosed partly by a semi-circle of mountains to the north and west, and is bounded on the northeast by the Mekong River. The plateau slopes gently down from the Korat, which is at an elevation of 600 feet above sea level, to its eastern extremity at Ubol, which is 300 feet above sea level. Two rivers, the Chee and the Mune, rise on the western flank of the plateau. They run parallel across the table land to join at Ubol, near the Indochina boundary, and then flow into the Mekong. Much of the plateau is undulating to rolling, dotted here and there by occasional hills of quartzitic sandstone and a few small shallow lakes.

This is a poverty-ridden portion of the country--of impoverished soil and adverse climate. Much of the land area is still unexplored; large sections are subject to the Monsoon climate. Although sections flood during the rainy season, they suffer water shortages during the dry season from November to May. Soils for the most part are fine, sandy loams, which are extremely low in fertility.

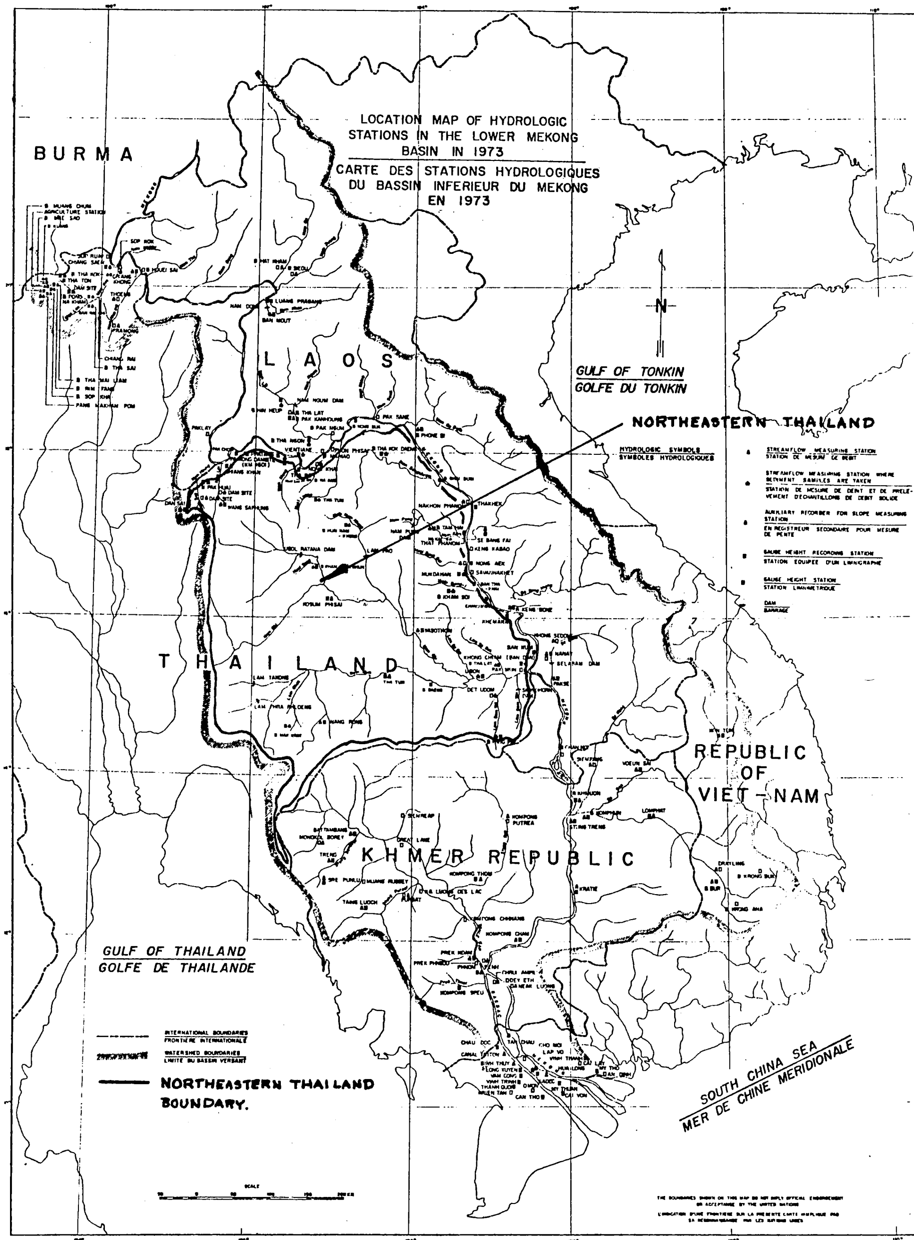


Figure 1. Map of Northeastern Thailand and Related Area

Source: (1)

The climate within the northeastern Thailand study area is tropical, with the minimum temperature considerably above freezing. The climate is influenced primarily by the Monsoon, and to a lesser extent, by the intropical front and cyclonic storms. The Monsoons are designated as the Southwest Monsoons, and the Northeast Monsoons by the movement of the air masses over the basin.

Historically, flooding of Northeastern Thailand is caused mainly by the flood flow of the Mekong River. Additional damage results from flooding caused by the backwater effect from tributaries unable to drain into the Mekong River. Every year, floods inflict substantial damage, especially in the Vientiane Plains and Nong Khai areas. The 1966 Mekong flood, which is one of the highest of record in this reach of the river, caused heavy losses to public utilities, business, personal property, and road systems, and destroyed approximately 18,300 hectares (46,000 acres) of the rice crop in the Vientiane, Laos, and Nongkhai, Thailand, areas.

Northeastern Thailand seeks the development of its water resources in terms of hydroelectric power, irrigation, navigation improvement, flood control, and in various related fields, with a view to improve the welfare of the people.

Flood discharge from a drainage basin may affect man's home or his livelihood, and may even endanger his life. It is also a phenomenon that occurs erratically in time and varies widely from one place to another.

Regional flood frequencies are the basic requirement for the planning design and operation of multipurpose water projects. Where the flood frequencies analyses are adequate, water projects can be undertaken with added assurance of success, since more of the available water resources can be safely developed, and vice versa.

The general objective of this study is to find methods of explaining the variations in flood magnitude throughout northeastern Thailand, so that flood freqency relationships may be predicted for any location in any gaged or ungaged basin.

The specific objective of this research is to find the equations needed to predict flood flows based on watershed and climatic variables for return periods of 2, 5, 10, 25, 50, and 100 years.

Synopsis of Following Chapters

Chapter II contains a review of literature on regional frequency analysis, water resources in northeastern Thailand and digital computer models for stream flow.

Chapter III is concerned with hydrologic information of northeastern Thailand, such as topography, climatology, drainage, geology, soil and its structure.

In Chapter IV, mathematics of regional frequency analysis, multiple regression analysis and weighted least squares theory are explained. The statistical model of regional flood frequency analysis, limitations, applications, and maximum flood record of northeastern Thailand are presented and discussed in Chapter V.

Chapters VI and VII are the summary, conclusions, and suggestions for future study.

CHAPTER II

LITERATURE REVIEW

Regional Frequency Analysis

Clarke-Hafstad (2) worked on the reliability of the frequency determinations of station-year rainfall, which is the combination of records of stations in an area, and using this as a single record for the midpoint of the area under consideration, she tried to develop a method to find the reliability of this combination by the number of times that a certain amount of rainfall has occurred at each station within a certain number of years. Then, from this number of occurrences, she gave the upper and lower limits about the average frequency of that amount of rainfall by a method that they had developed.

Her method of calculating dependence of the stations within an area did not take into consideration the time of occurrence of the events. For example, considering three stations with nine years of records each, 20 mm of rainfall may be recorded three times in all of the three stations in nine years, but the years of occurrence may be different at each.

Longbein (3) developed a test to define a homogeneous region for regional flood frequency analysis practiced by the United States Geological Survey. At each station within a region a study of ten-year floods as estimated from its probability curve is required for this homogeneity test. The ratio of ten-year flood to mean annual flood (which has a recurrence interval of 2.33 years according to Gumbel's extreme value distribution) is found for each station within the region, then these ratios are averaged to obtain the mean ten-year ratio for the area. From the probability curve of each station, the recurrence interval corresponding to the mean annual flood times the averaged ten-year ratio is found and plotted against the so-called "effective or adjusted length of record" on a test graph. The effective (adjusted) length of record is the number of years of actual record plus one-half the number of years of the record.

The test graph is constructed on the basis of extremal distribution. If the points fall within the two control curves, then that region is considered to be homogeneous. The control curves represent a range of variations equal to two standard deviations of the reduced variate on the ten-year flood (indicating 95 percent reliability). The estimated deviation of the reduced variate is

$$\sigma y = \frac{e^y}{\sqrt{n}} \sqrt{\frac{1}{T-1}} \tag{2.1}$$

where T is recurrence interval, n is the number of years of record, y is called the reduced variate, and is given by the equation:

$$y = - \log e \left[- \log e \left(1 - \frac{1}{T}\right) \right] \tag{2.2}$$

for T = 10 years, y = 2.25 (from the equation of reduced variate given below), and e^y = 9.49. Then equation (2.1) becomes

$$2\sigma y = 6.33/\sqrt{n} \tag{2.3}$$

The return period T_L and T_U corresponding to $y - 2\sigma y$ and $y + 2\sigma y$ define the lower and upper limits of the control curves for a value of n.

Dalrymple (4) after the analyses of records from 7,000 sites in the United States, developed a method to determine the magnitude and frequency of momentary peak discharges at any place on a stream, whether a gaging station record is available or not. This method was based on Longbein's previous work.

The method was based on statistically dependent records of gaging stations at hydrologically homogeneous areas. Rather than adding several short records to produce a long term record and finding the average, taking the median of the records of the stations for each event could yield better results in frequency analysis for that area. By this method, five records of twenty years each when combined give only a twenty-year record, but it is considered that each year of flood has been measured five times. The median of these five values is assumed to give a better measure of the frequency characteristics of those events.

Benson (5) made a study of floods in the New England states (U.S.A.) using the multiple linear regression and correlation techniques. From this analysis, the annual peak discharge in cubic feet per second for a measured interval of T years was found to be

$$Q_T = aA^b S^c S_T^d I^e t^f O^g \qquad (2.4)$$

where

A = drainage area (sq. mi.)

S = slope of main channel (ft/mi)

S_t = surface storage area plus 0.5%

I = 24-hr rainfall (inches) of recurrence interval of T years

t = average temperature in January ^oF before freezing

O = orographic factor

b, c, d, e, f, g, = estimated coefficient from a multiple linear regression relationship of the type:

$$\log Q_T = \log a + b \log A + c \log S + d \log S_T + e \log I + f \log t + g \log O \quad (2.5)$$

Benson and Matalas (6) used a regression technique to generate stream flow at ungaged sites from regional data in the United States. The process utilizes multiple regression relating monthly or annual average flows to the physiographic and climatological factors of the region.

The United States Geological Survey (7) also used this technique. Analysis of historic records is of little value in flood frequency studies for an ungaged watershed or watersheds with only a few years of record. The U. S. Geological Survey has summarized flood data and presented regional frequency methods for the United States. They separated the United States into several areas, and used multiple regression to fit streamflow in several recurrence intervals as a function of characteristics of drainage area and climatology.

Literature Review of Water Research in Northeastern Thailand

Molagool's study (12) of the water balance in northeast Thailand was calculated for representative localities using Thornethwaite's (49) method for assessing potential evapotranspiration which, although hitherto not extensively applied in tropical regions, yields very reliable results, the assessed runoff agreeing well with the observed runoff. Infiltration during the wet season amounts to about 20 mm/month. Overall, 80 percent of the rainfall is returned to the atmosphere by evapotranspiration, 7½ percent is lost in infiltration, and the remaining 12½ percent runs into the Mekong River. There is a soil moisture deficit over the whole area amounting to 400-700 mm, which is most extreme around Chaiyaphum, least severe in the extreme northeast where the rainfall is highest. Comparing supply and demand, it is evident that no more than 10-15 percent of northeast Thailand can be irrigated for year 'round crop production without bringing in additional water from the Mekong.

Pravatmuang (8) reported on the hydrology of the lower Mekong River with particular reference to the Pa Mong Project. He analyzed the hydrologic conditions of the Mekong River over a distance of 180 km stretching from Vientiane to Kratie, in respect to mean, maximum and minimum flow, seasonal variation, seasonal variation, flow duration and flow recession, based on data compiled by the Harza Engineering Company for the Committee for Coordination of Investigation of the Lower Mekong River Basin, with an assessment of river flow parameters for the proposed Pa Mong project site 30 km upstream of Vientiane, Laos.

Discharge records covering the period 1923-1961 at Vientiane and Kratie and at the three intermediate stations (Thakek, Mukdahan, and Pakse) were used in the evaluation to test for consistency and to establish the geographic variation of the various parameters over the area of interest, which may be summarized briefly as follows:

	Vientiane m^3/sec	Kratie m^3/sec
1000-year flood	28,112	95,369
100-year flood	23,818	79,967
mean flow	4,210	13,912
100-year drought	622	1,200
1000-year drought	559	1,130

The United States Bureau of Reclamation (9) published the "Pa Mong Project Phase I Report" which related to water research of northeastern Thailand. From this preliminary report, it was determined that more detailed investigations of the proposed project were justified. These studies were carried out, and by Janury, 1970, the Bureau had completed the "Stage One Feasibility Report" covering the initial power portion of the project and an initial increment of irrigation development. This report was supplemented by a special "Optimization Study and Interest Rate Sensitivity Analysis" dated July, 1971. The phase II report, published in 1972 by the Bureau of Reclamation, incorporated data from the state one feasibility report, and provides an inventory of possible future irrigation development project and other possible ultimate developments which also give some details about water research in northeastern Thailand.

Pinkayan and Sahagun (11) did a hydrologic study of the Thung Ma Hiu irrigation project in the Pibulmangsahan district of Ubon Rajathani province. The study dealt with the problems of hydrology drainage and flood control improvement in the project area and also related to northeastern Thailand.

Literature Review of Digital Computer Model for Simulation of Stream Flow

Several digital computer models were assessed by the author as to their application for simulation of stream flow records for future water research in northeastern Thailand.

The SSAR model was redesigned with significant improvements in 1966 and 1967, in conjunction with a training program in Systems Analysis conducted in Portland, Oregon, for Southeast Asian Engineers (39). The program was written in FORTRAN for use in the IBM 360 Computer system expected to be available for use by the Mekong Committee in Bangkok, Thailand, and by the North Pacific Division Office of the Corps of Engineers of the United States. This rewritten program intended for worldwide use indicated the ability to synthesize streamflow from a watershed with almost any combination of characteristics, whereas the previous version of the program was oriented mainly to application in the Pacific Northwest United States.

Preliminary basin characteristics and relationships affecting runoff were developed for many of the Lower Mekong subbasins that included the northeastern part of Thailand, during the training program in Portland, and this work has been continued in Bangkok, Thailand. Reconstitution studies have been made for all of the gaged areas of major tributaries. Design floods for three projects on the Lower Mekong were developed by Rockwood and Anderson (40). Twenty-eight subbasins and fourteen channel reaches were included in that analysis, utilizing basic hydrology relationships generalized from the work carried out under the training program.

The SSAR watershed model incorporates rainfall-runoff relationships and other factors in the hydrologic cycle for use in developing streamflows synthetically. Figure 2 is a schematic diagram of the SSAR model. Rainfall runoff versions of the model have been developed for use with Metric or English units.

Hydrologic elements and relationships illustrated in Figure 2 are described briefly as follows:

a) Rainfall and snowmelt (optional, not used in Mekong basins) are basic time-dependent data, specified by the user or computed by index relationships of point values.

b) Moisture Input (MI) is that quantity of water resulting from rainfall distributed uniformly on a given watershed area, within a specified period of time.

c) Soil Moisture Index (SMI) is used with an appropriate runoff relationship to separate the moisture input into two parts: 1) the runoff, and 2) soil moisture increase.

d) Evapotranspiration Index (ETI) is used to compute the reduction in soil moisture.

e) The Baseflow Infiltration Index (BII) is used to separate runoff into components of baseflow and direct runoff.

f) Baseflow is that component which is routed with a relatively long period of time before appearing as streamflow.

g) Direct Runoff is divided into surface and sub-surface components, and these two components are then routed separately.

h) Computed Streamflow is the sum of the routed components.

Unfortunately, the SSAR model is the best for simulation of

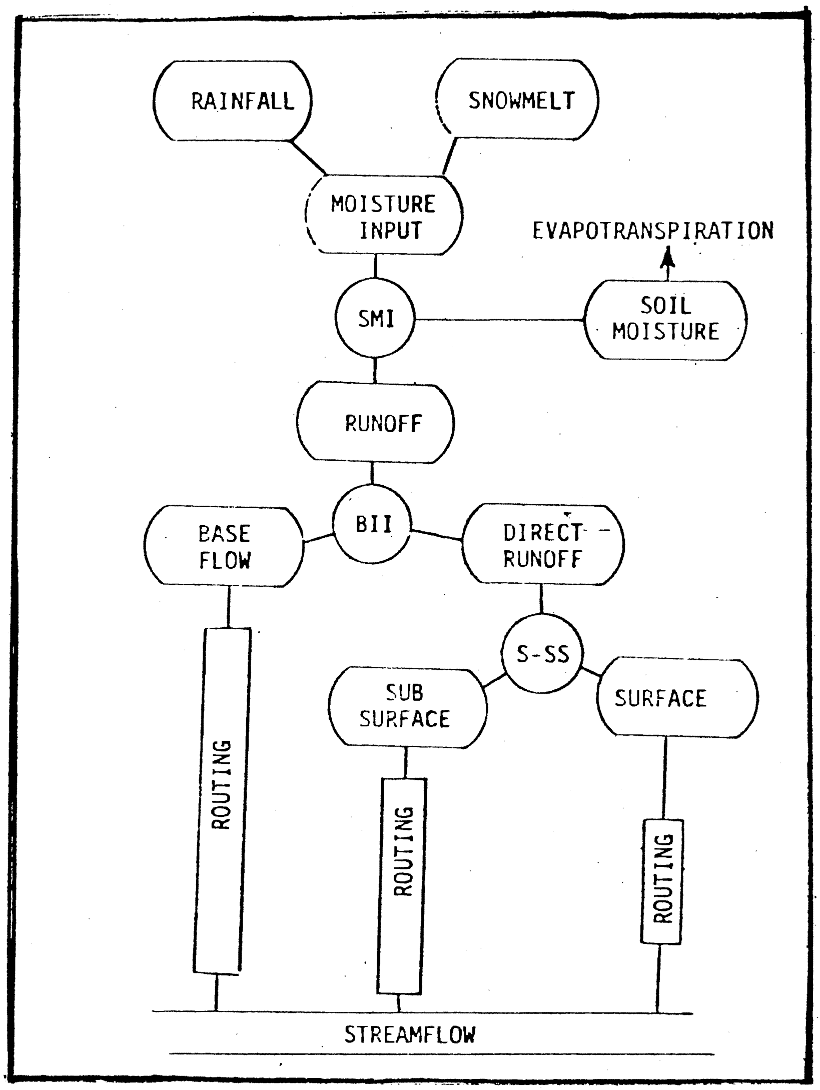


Figure 2. Computation of Basin Runoff SSAR Model

Source: (38)

streamflow for short periods of time (46). Therefore, the author could not use the SSAR model in this research.

Martin discussed the evolution of the conceptual model of streamflow (41) in the U.S.A. It may be useful for future water resources research in northeastern Thailand; however, many of the parameters used in these models are currently unavailable for northeastern Thailand, and considerable effort would be required to obtain them.

United States Department of Agriculture Hydrological Laboratory (USDAHL) Model

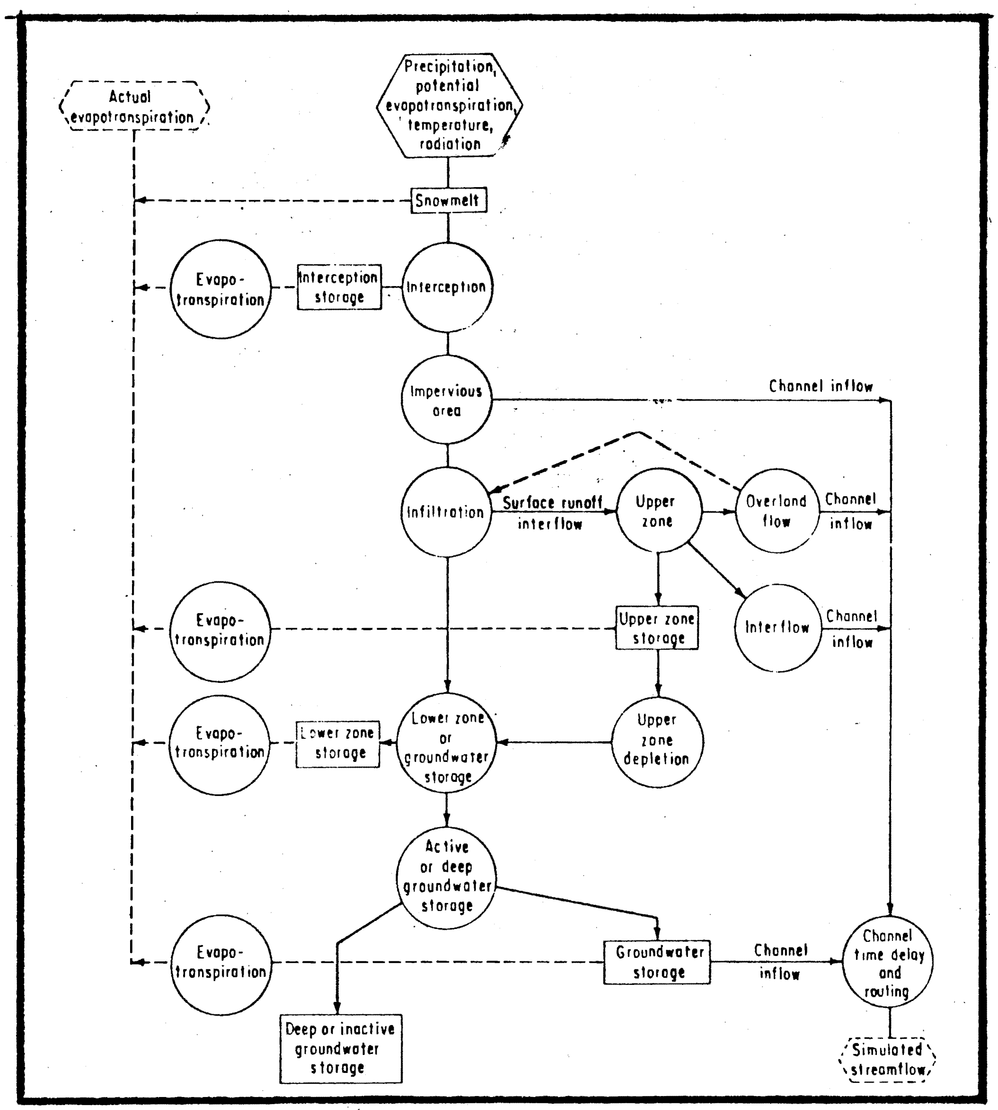
The USDAHL model was developed using data from a 2.37 square mile experimental watershed at Coshocton, Ohio. Simulations were originally made on a single storm basis, and later expanded to synthesize a period of continuous record.

The USDAHL model was designed for very small watersheds; the extent of testing on large watersheds is unknown. Nevertheless, it does not seem useful for watersheds of the size normally encountered in forecasting. Lindsley (43) feels it is not particularly adaptable to the large watershed.

Stanford Watershed Model IV (SWM IV)

A milestone in the use of the computer to simulate and thus predict river from rainfall was presented by a program developed at Stanford University. The Mark IV version (45), completed in 1966, was the result of six years of digital hydrologic simulation. Subsequently, the commercial applications of the program and its further evolution have been carried out by a private firm, Hydrocomp, set up by the originators of the program. The Mark IV program, which is used on an IBM 360/67, had the capability of simulating with considerable effectiveness, the hydrological behavior of complex river systems. With current information on rainfall and snow runoff, the effects of a flood wave could be calculated at any point down stream.

Basically, the simulation model was designed to accept input from any number of recording gages, and to produce flow at a series of points in the stream channel downstream. Streamflow could be calculated at several locations (flow points) in the stream channel--the area above each location being divided into segments selected from topographical considerations (one or more segments for each recording rain gage). The general model included a data section, and involved reading data cards and storing the data on magnetic tape for use in the simulation. The input to the simulation consisted essentially of options for controlling the program and of fixed parameters determined by watershed characteristics, such as mean rainfall or watershed area. Figure 3 gives the input sequence. The output provided a description of the streamflow conditions at a series of points in the stream channel system, and a number of optional data related to the basic output. The entire simulation model consisted of approximately 1300 statements. The significance of the model was that it could make information on historically recorded flows and simulated streamflows with a statistical estimate of simulation accuracy, and that it offered the opportunity to search out and evaluate all of the hydrometeorological records existing in the region.



Flow Chart

Figure 3. Stanford Watershed Model IV

Source: (47), p. 322

United States Geological Survey Watershed Model

This model is patterned after the Stanford watershed model, although it is a much simplified version. Its design purpose was to analyze storm peaks. It establishes antecedent soil moisture conditions, utilizes an infiltration equation, a two-level moisture storage system for water balance accounting, and linear storage and translation methods for routing to the basin outflow point. The pilot study for the model was on a 5.41 sq mi basin in the Blue Ridge Mountains. Tests have shown that this model has some degree of competence, but extensive testing of it does not appear to have been done. Since its emphasis was on flood peaks, it was designed to only simulate the surface runoff component of the flood hydrograph, and baseflow and seepage were simply not considered. Since these are the principal components of low flow, this model is not suitable for simulating low flow.

National Weather Service River Forecast System (NWSRFS)

The acronym NWSRFS stands for National Weather Service River Forecast System, and refers to the system described in NWS HYDRO 14 (42). This system was assembled by the Hydrologic Research Laboratory (HRL) of the National Weather Services Office of Hydrology, in Silver Springs, Maryland, and includes programs to process data, compute mean basin precipitation (MBP), optimize parameters, verify model parameters, and produce operational river forecasts.

The heart of this system is the model of the hydrologic cycle. Selection of this portion of the model was based on a statistical analysis of three watershed models: the SSAR model, the Sacramento model, and a version of the Stanford Watershed IV (SWM IV) model as modified by the HRL. The decision of which to choose was narrowed down to a choice between the modified SWM IV and the Sacramento model, and on the basis of statistical analyses completed by August, 1971, the modified SWM IV was chosen. It should be noted that testing performed after that date showed that there was no significant difference between the two, and Burnash (44) cited that the latest version of the Sacramento model is considerably better than the one involved in the testing. It is interesting to note that the HRL is now adopting the land phase of the Sacramento model to replace the land phase of the modified SWM IV currently used in the NWRFS (see Figure 4).

Sacramento Model

This is the model developed from the Generalized Streamflow Simulation System, which was documented in March, 1973 (44). It attempts to simulate streamflow by simulating all of the significant components of the hydrologic cycle in a simplified manner, which is consistent with observed soil moisture profiles. Each variable in the model then has a recognizable counterpart in the physical world. Data inputs are for twenty-four increments and were not justified for the average size basin (60-1200 sq mi). This model will be described through a description of its various components (see Figure 5) for simplified flow chart of the soil moisture accounting system of the model.

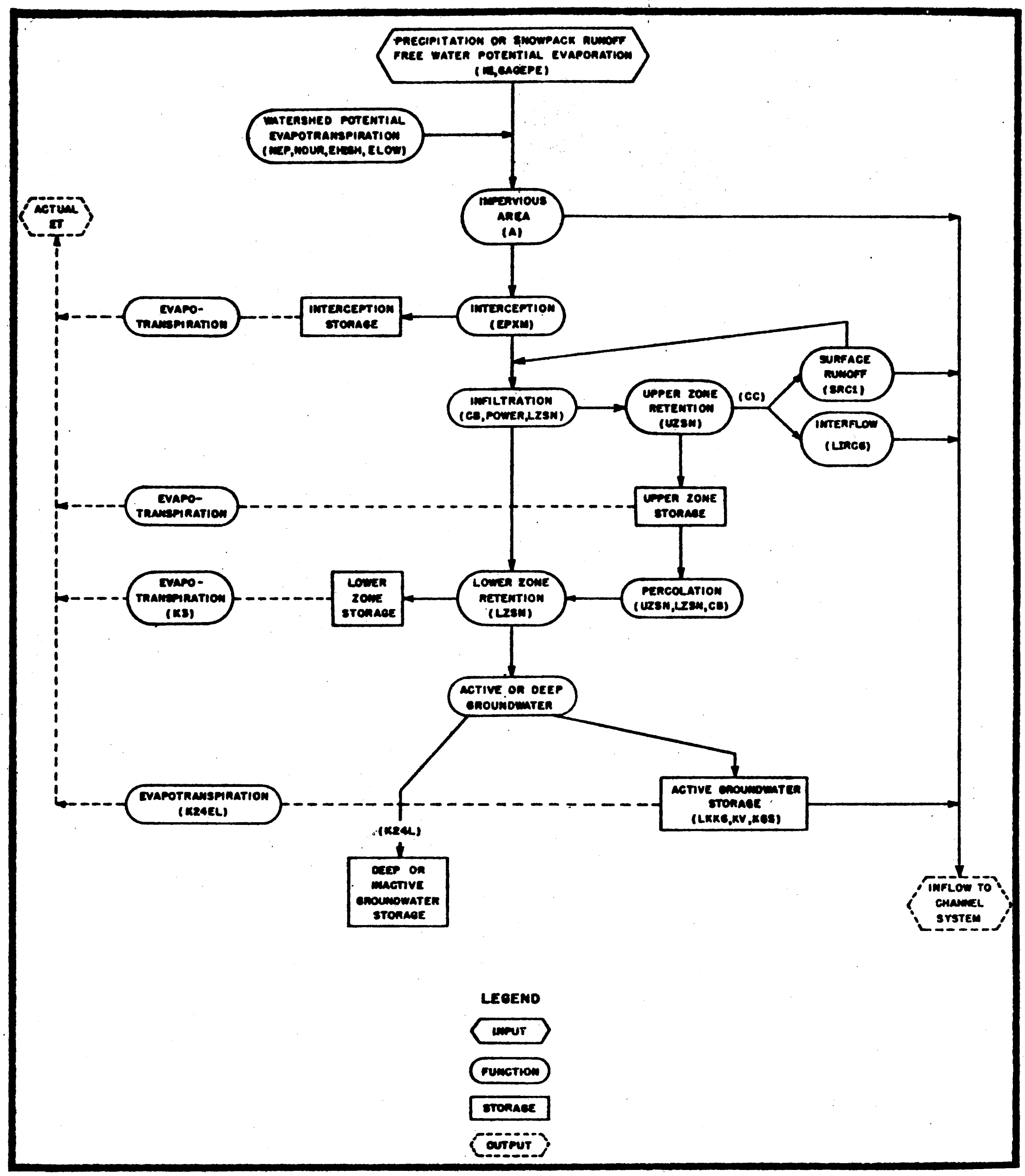


Figure 4. Flowchart of Soil Moisture Accounting Portion of the National Weather Service River Forecasting System

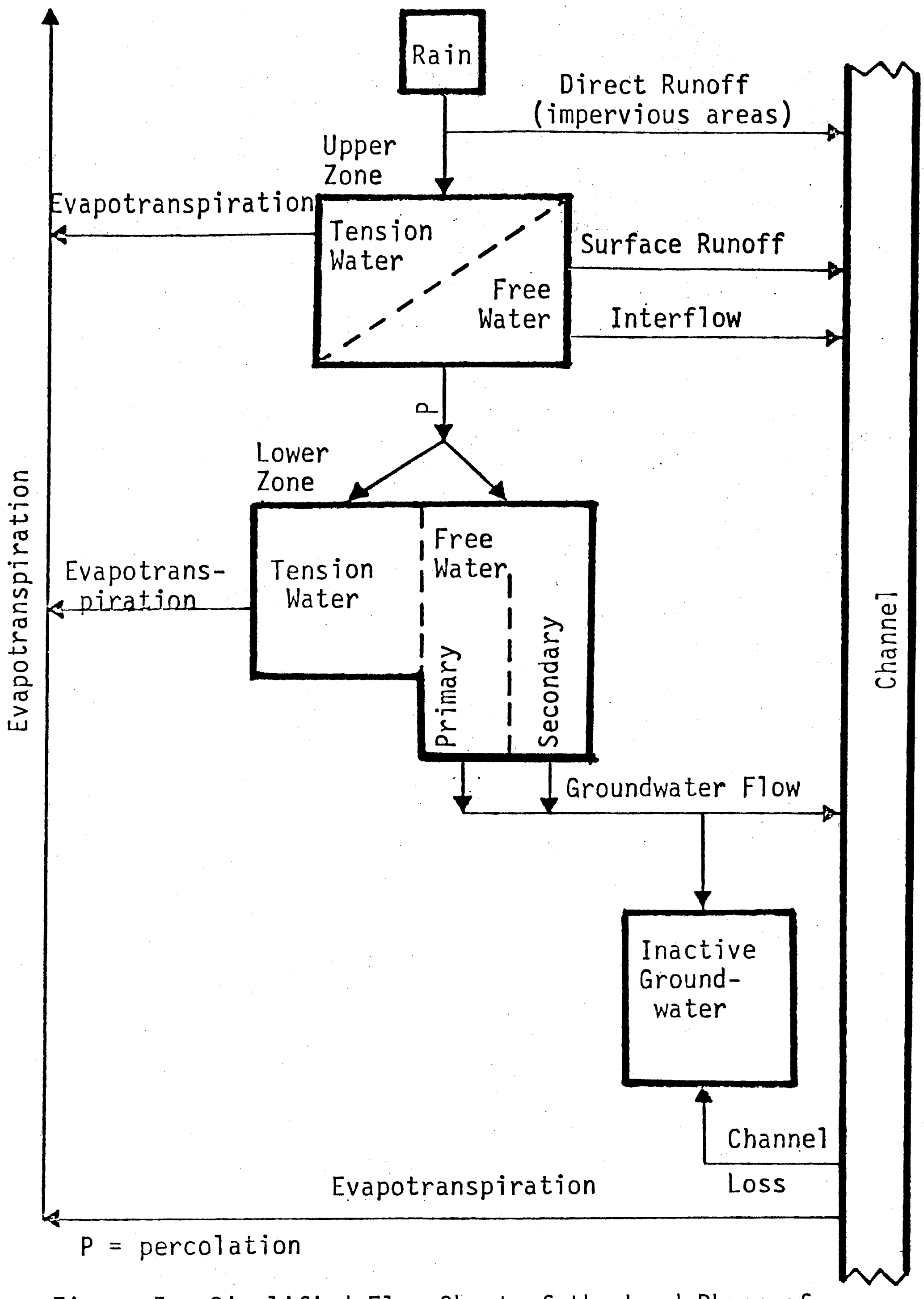


Figure 5. Simplified Flow Chart of the Land Phase of Sacramento Model

Source: (40)

CHAPTER III

HYDROLOGIC INFORMATION FOR NORTHEASTERN THAILAND

Topography, Drainage, Geologic Structure, and Soil

Northeastern Thailand is bounded by the Mekong River on the north and east, the Phanom Daugrek escarpment on the south, and the Petchabun Ridge on the west, the whole comprising a very flat inland basin or plateau tilted gently toward the southeastern corner. There are two low hills south of Udon Thani and Sakon Nakhon. Apart from those and the hills on the southern and western borders, the plain presents an aspect of unrelieved flatness, stretching to the horizon as far as the eye can see. The western edge of the plain at the foot of the Petchbum Mountains has an elevation of about 200 m (10). Along the Mekong, the elevation is for the most part less than 150 meters. The highest peak is Khao Laem (1328 meters).

The main rivers are the Mune and the Chee. Together, these drain four-fifths of the region. The Mune rises near Nakhon Ratchasima and flows eastward through Ubon Ratchathani to the Mekong, draining the northern slopes of the Phanom Dangrek Mountains. The Chee drains all of the western portion of the plain and most of the interior, flowing southeast to meet the Mune at Ubon. The combined drainage area of the two rivers is 125,500 square kilometers.

La Moreaux, et al. (37) cited that the region is structurally unique in occupying the center of a series of concentric mountain folds that encircle Burma, Thailand, Malaya, Indonesia, and the Phillipines. Except for a few small outcrops of basalt in the south and outcrops of limestone and igneous rocks along a north-south trending ridge between Loei and Udon, the plateau is made up of a series of fine-grained sandstone and shale beds overlain in valley depression by river terrace deposits. The beds are believed to have a total thickness of 1200 meters. Over a large part of the region embracing Khon Kaen, Kalasin, Ubon Ratchathani, Surin, Nakhon Ratchasima, and Chaiyaphum, the near-surface rocks are fine- to medium-grained sandstones, tan to pinkish-red in color, interbedded with mottled purple and gray fine sandy shale. These lithologic units are also found in the northeastern corner, north of Sakon Nakhon and east of Udon Thani and Nongkhai. Between these two areas and elsewhere around the perimeter in a strip of 10-15 km width, the surface rocks are massive, fine- to coarse-grained sandstones, some conglomeritic, of a variety of colors and interbedded with shale. Geological descriptions are not precise enough to differentiate between pervious and impervious formations, but in general aspects, the coarser sandstones and the upper strata, being the least consolidated, are the most pervious. Alluvial beds of recent origin include clays, silts, sands and gravels, some of which are highly pervious.

As natural rock surfaces are rarely exposed in the interior and few borings have been put down, the structure of the plain must be largely conjectural. On such geological evidence as there is, it seems that the formations are slightly dished into a shallow structural basin, dipping at very low angles to the center, the stratigraphy being exposed only in the hills at the edge.

Paddleton (3) cited that he classifies the soil into four main types: a) Khorat, fine sandy loams, b) Roi Et, fine sandy loams, c) Gula Ronghai, silt loams, and d) sandy soils derived from quartzite and silicious sandstone hills.

The first of these is found on foothill slopes, often with laterite; it is not usually cultivated. Roit Et fine sandy loams are the lower portions of this soil type which are diked and used for growing rice. Gula Ronghai silt loams are found in the lower depressions of the plain along the banks of the Mune, Chee, and Songkram Rivers, covered with sparse grass. The surface soil is light grey to whitish silt up to 30 cm in thickness, under which there is a heavy grey clay that sometimes has scattered iron or magnesium concretions in it. The last type occurs in the Phu Phan range south of Sakon Nakhon and the Petchabun hills to the west. The four groups are roughly of equal extent.

Climatology

Molagool (12) reported that the climate of the region is characteristically monsoonal. The southwest monsoon caused by low pressure over Central Asia, brings copious rainfall to the whole of Thailand (see Figures 6 and 7). The U. S. Bureau of Reclamation stated that (14)(15) this air mass moves in from the south, the air circulating in a counterclockwise direction. It picks up moisture from the Indian Ocean and produces rains starting about mid-May, with the heaviest occurring in August and September, creating what is known as the rainy season,

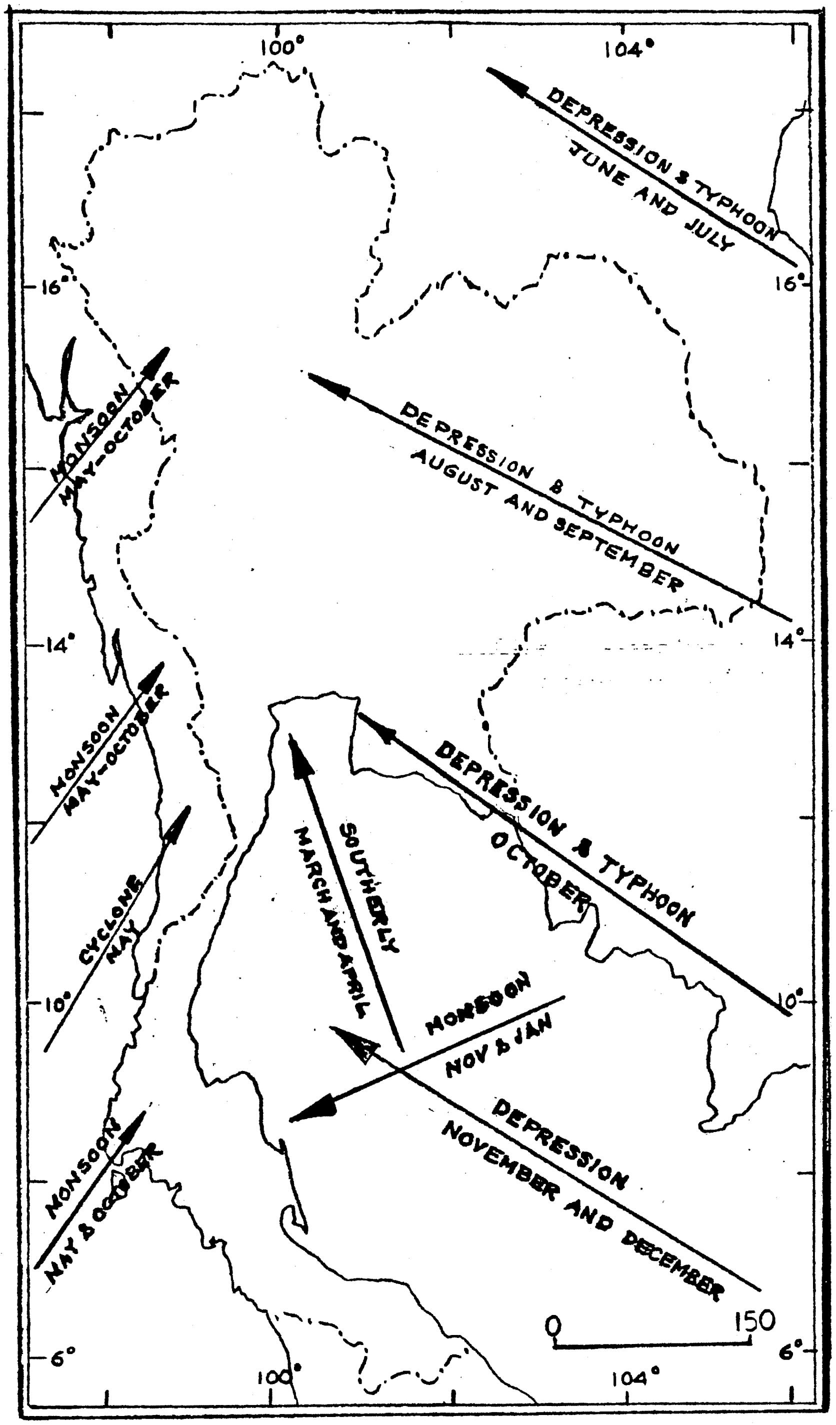


Figure 6. Map of Thailand and Air Stream Dominating Climatic Conditions

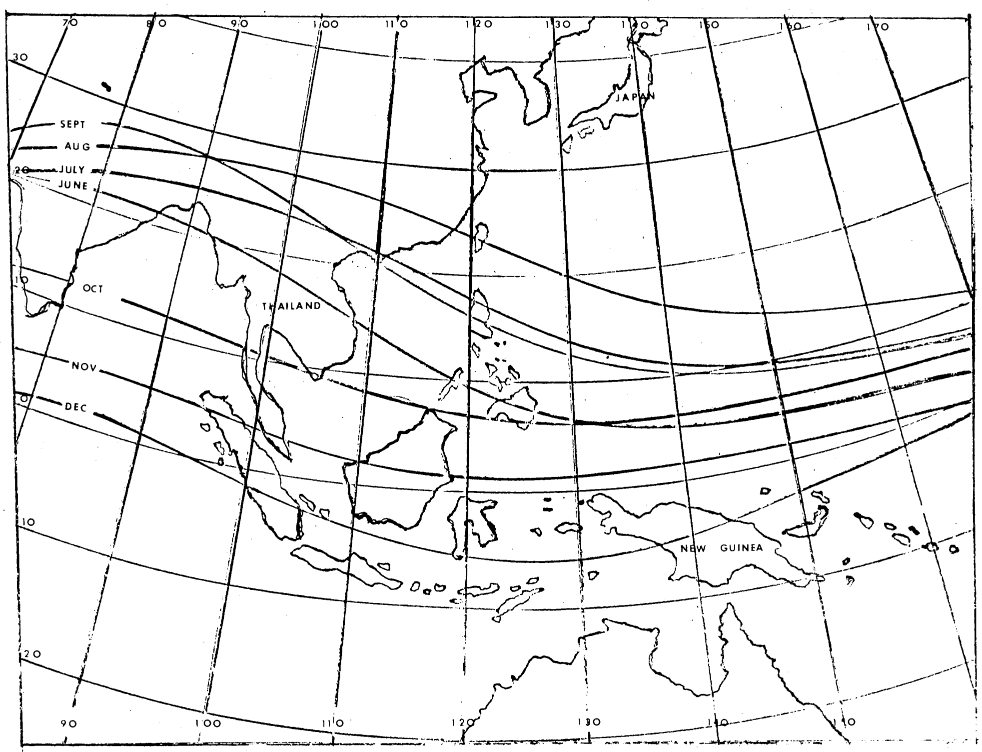


Figure 7. Mean Positions of the Inter-Tropical Convergence Zone at Different Months of the Year

lasting until mid-October. Occasionally, the continental Australian air mass will shift enough to the west to displace the southwest monsoon from the Indian Ocean. When this happens, drought conditions and crop failures may be expected over the basin area. The low runoff year of 1957 was the result of this weather phenomenon.

Starting in May, precipitation increases steadily as the wet season progresses, until a maximum of 250 mm is reached in September. Accompanying this, there is a slight rise in humidity and simultaneous decrease in temperature and radiation. The average wind velocity remains fairly steady at about 1.5 on the Beaufort Scale (5 miles an hour).

Precipitation falls off rapidly in October and November, in spite of occasional tropical storms that move inland from the South China Sea, bringing torrential rainfall near the coast but weakening rapidly as they penetrate inland.

The Reverse Airstream - the Northeast Monsoon

The U. S. Bureau of Reclamation (14)(15) also reported that cold air masses originating in the polar region move southward across Siberia and the mainland of China. This air mass has a clockwise motion and is cold and dry. The influence of this air mass is felt from mid-October until the middle of February when the weather is cool and practically no rain occurs. Following this monsoon is a transition period when the polar Pacific air is modified by tropical heat and moves into the area from the east and southeast. This gives a period of hot, dry weather from mid-February to mid-May, called the hot season. The intertropical front occurs where the southwest monsoon and the cold air masses from the north meet. It is along this front that the heavy rains occur during the wet season. This is sometimes referred to as the "trough," and rain can be predicted at its location.

The cyclonic storms that sweep into the mainland from the Pacific Ocean are the cause of intense precipitation. If two such storms occur with the second following the first by about one week, flooding is likely to occur. Actually, only about one out of ten cyclonic storms reach the mainland of Southeast Asia, and these generally weaken as they move inland. There are three types of cyclonic storms classified by the wind velocities attained in their generation:

1) depression: wind up to 61 kilometers per hour

2) tropical storm: wind 62 to 117 kilometers per hour

3) typhoon: cyclonic winds greater than 117 kilometers per hour.

The northeast monsoon starts in December. The temperature falls from 26°C to 22°C as the cooler, drier air flows south. For the next three months, rainfall is negligible. Temperatures rise quickly in January, then more slowly to a maximum of 30°C in May. During this period, the weather is hot and dry, moderated slightly by light breezes, cool nights, and very occasional light showers. Relative humidity reaches a minimum of 60 percent in March. Statistics concerning these are set out in Tables XXII-XXXIV in Appendix A (14)(15)(16)(17).

CHAPTER IV

MATHEMATICS OF REGIONAL FREQUENCY ANALYSIS

Introduction

Riggs (18) stated that regional analysis is concerned with extending records in space as differentiated from extending them in time. Because stream flow records are collected at only a few of the many sites where information is needed, gaging station information must be transferred to ungaged sites.

The specific purposes of a regional analysis, then, are to provide estimates of the characteristics of the frequency distributions at the ungaged sites, and to improve estimates of the frequency distributions of flow characteristics at gaged sites. Consider, for example, a frequency curve of annual floods derived from 50 years of record. This frequency curve is an estimate of the population frequency curves. It will differ from the true curve, however, because a 50-year sample of floods is never completely representative. Frequency curves for other streams would also differ from their respective true curves. If these several curves were based on samples from the same population frequency curve and if they were independent of each other, then we would expect that an average of the several curves would be a better estimate of the population curve than any one of the samples. This averaging of curves can be accomplished by regional analysis.

No group, or even pair, of stream sites would have the same population frequency distribution of floods. The true distribution at a site depends on a great many factors, the principal ones being basin characteristics such as size, topography, geology, and climate. Thus, the variability among a group of flood frequency curves is made up of two components: chance variation due to sampling, and variation due to differences in basin characteristics. A regionalization procedure should average the chance variation but should maintain the variation due to basin characteristics. This is a difficult task because the total variation cannot be neatly separated into the two types of variation. The degree of success attained by a given method of regionalization depends on the relative sizes of the variations due to chance and those due to differences in basin characteristics, the degree of independence of the samples at the various gaging stations, the quality of the mathematical representation of basin characteristics, and the general suitability of the method.

Log Pearson Type III

A frequency curve relates magnitude of a variable to frequency of occurrence. The curve is an estimate of the cumulative distribution of the population of that variable and is prepared from a sample of data.

Frequency curves have many uses in hydrology. Flood frequency curves are widely used in the design of bridge openings, channel capacities, and roadbed elevations; for flood plain zoning, and in studies of economics of flood protection works. Frequency curves of annual low flows are used in design of industrial and domestic water supply systems, classification of streams as to their potential for waste dilution, definition of the probable amount of water available for supplemental irrigation, and maintenance of certain channel discharges as required by agreement or by law. Frequency curves of annual mean flows are sometimes used in studies of the carryover of annual storage (19).

Frequency curves also provide a means of classifying data for use in subsequent analyses. For example, Benson (20) used intensity of rainfall for a given frequency in his regional flood frequency analysis for New England, and Riggs (21) used a frequency curve of runoff in excess of assured flow in a forecasting problem. Many other applications have been and can be made.

In 1967, the U. S. Water Resources Council recommended the use of the Pearson Type III distribution with log transformation of the data (log-Pearson Type III distribution) as a base method for flood flow frequency studies (22). As pointed out in that report, further studies were needed covering various aspects of flow frequency determinations.

In 1974, the U. S. Water Resources Council provided an extension and updated its previous report (23). It provides a more complete guide for flood flow frequency analysis, incorporating accepted technological methods with sufficient detail to promote uniform application. This guide is limited to defining flood potentials in terms of peak discharge and exceedence probability at locations where a systematic record of peak flood flow is available.

Multiple Regression Analysis

General

Yevjavich (25) stated that the association of three or more variables can be investigated by the multiple regression and correlation analyses.

The multiple regression relation may be expressed in the form

$$Y = f(X_1, X_2, X_3, X_4, X_5, \ldots) \tag{4.1}$$

where

$X_1, X_2, X_3, \ldots X_m$ are m independent variables. This equation gives the estimate of Y for given values of all other variables.

If equation (4.1) is linear, the regression is referred to as MULTIPLE LINEAR REGRESSION and the association is MULTIPLE LINEAR CORRELATION.

Because linear equations are easier to treat than are nonlinear multiple relations, variables of nonlinear relations in hydrology are often transformed to linear relations for multiple regression analysis.

Linear Regression With Several Variables

If there are m variables to correlate, including one dependent and m-1 externally independent, the general equation for multiple linear regression is

$$Y = B_0 + B_1X_1 + \ldots\ldots + B_iX_1 + \ldots\ldots + B_mX_m \tag{4.2}$$

where B_0 is the intercept and B_i is the multiple regression coefficient of the dependent variable Y on the independent variable Xi with all other variables kept constant.

The principal results for the multiple regression model (equation 4.2) can be shown in matrix form.

To express the multiple linear regression model (equation 4.2):

$$Y_i = B_0 + B_i X_{i1} + B_2 X_{i2} \ldots\ldots + B_m X_{im} + \varepsilon_i \tag{4.3}$$

in matrix form, we need to define the following matrices for the n observations:

(4.4)
$$\underset{n\times 1}{Y} = \begin{bmatrix} Y_1 \\ \vdots \\ Y_n \end{bmatrix}$$

(4.5)
$$\underset{n\times(m+1)}{X} = \begin{bmatrix} 1 & X_{11} & X_{12} & X_{1,m} \\ 1 & X_{21} & X_{22} & X_{2,m} \\ & & & \\ 1 & X_{n1} & X_{n2} & X_{n,m} \end{bmatrix}$$

$$\underset{(m+1)\times 1}{B} = \begin{bmatrix} B_0 \\ B_1 \\ \\ B_m \end{bmatrix}$$

(4.6)

$$\underset{n\times 1}{\varepsilon} = \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \\ \varepsilon_n \end{bmatrix}$$

(4.7)

In the general form, the multiple regression model (4.3) is then

$$\underset{n\times 1}{Y} = \underset{n\times(m+1)}{X}\underset{(m+1)\times 1}{B} + \underset{n\times 1}{\varepsilon} \tag{4.8}$$

where

Y is a vector of observations

B is a vector of parameters

X is a matrix of constants

ε is a vector of independent normal random variables with expectation $E(\varepsilon) = 0$ and

variance-covariance matrix $\sigma^2(\varepsilon) = \sigma^2 I$.

Consequently, the random vector Y has expectation:

$$E(Y) = YB \tag{4.9}$$

and the variance-covariance matrix of Y is

$$\sigma^2(Y) = \sigma^2 I \tag{4.10}$$

<u>Least Squares Estimators</u>

Denote the vector of the estimates of the regression coefficients B_0, B_1 ....., B_m as b:

$$\underset{(m+1)\times 1}{b} = \begin{bmatrix} b_0 \\ b_1 \\ b_2 \\ \vdots \\ b_m \end{bmatrix} \tag{4.11}$$

The least squares normal equations for the general multiple linear regression (4.8) are:

$$\underset{(m+1)x(m+1)}{(X'X)'} \quad \underset{(m+1)x1}{B} = \underset{(m+1)n}{X'} \quad \underset{nx1}{Y} \tag{4.12}$$

and the least squares estimators are

$$\underset{(m+1)x1}{b} = \underset{(m+1)(m+1)}{('X')^{-1}} \quad \underset{m+1x1}{X'Y} \tag{4.13}$$

<u>Analysis of Variance Result</u>

Let the vector of the fitted values $\hat{Y}_i$ be denoted by $\hat{Y}$ and the vector of the residual terms, $e_i = Y_i - \hat{Y}_i$, be denoted by e:

(4.14) (4.15)

$$\underset{nx1}{Y} = \begin{bmatrix} \hat{Y}_1 \\ \hat{Y}_2 \\ \vdots \\ \hat{Y}_n \end{bmatrix} \qquad \underset{nx1}{e} = \begin{bmatrix} e_1 \\ e_2 \\ \vdots \\ e_n \end{bmatrix}$$

The fitted values are represented by

$$\hat{Y} = Xb \tag{4.16}$$

and the residual vector by

$$e = Y - \hat{Y} \quad (4.17)$$

Sums of Squares and Mean Squares

The sums of squares for the analysis of variances are:

$$\text{Sums of squares total} = SSTOT = Y'Y - n\bar{Y}^2 \quad (4.18)$$

$$\text{Sums of squares regression} = SSR = b'X'Y - n\bar{Y}^2 \quad (4.19)$$

$$\text{Sums of squares error} = SSE = e'e = Y'Y - b'X'Y' \quad (4.20)$$

The sum of squares total, as usual, has n-1 degrees of freedom associated with it. The sum of squares error has n-(m+1) degrees of freedom associated with it since m+1 parameters need to be estimated in the regression function for model (4.8). Finally, the sum of squares regression has m+1-1 = m degrees of freedom associated with it, representing the number of X variables X_1 ....., X_m for which a coefficient has been estimated.

Table I shows these analyses of variance results, as well as the mean squares MSR and MSE:

$$\text{(MEAN SQUARE REGRESSION)} = MSR = \frac{\text{sum of square regression}}{m} \quad (4.21)$$

$$\text{(MEAN SQUARE ERROR)} = MSE = \frac{\text{sum of square error}}{n-m+1} \quad (4.22)$$

The expectation of MSE is σ^2, as for simple regression. Neter and Wasserman (27) stated that the expectation of MSR is σ^2 plus a quantity which is positive if any of the B_k (k = 1, ..., m) coefficients is not zero. For instance, when m+1-1 = m = 2, then

$$E(MSR) = \sigma^2 + B_1^2\ \Sigma(X_{i1} + \bar{X}_1)^2 + B_2^2\ \Sigma(X_{i2} - \bar{X}_2)^2 +$$

$$2B_1B_2\ \Sigma(X_{i1} - \bar{X}_1)(X_{i2} - \bar{X}_2)\ \ /2\ . \tag{4.23}$$

Thus, if both B_1 and B_2 equal zero, $E(MSR) = \sigma^2$. Otherwise, $E(MSR) > \sigma^2$.

TABLE I

ANOVA TABLE FOR GENERAL LINEAR REGRESSION MODEL (4.24)

Source of Variation	Sum of Square	DF	MS
REGRESSION	$SSR = b'X'Y' - n\bar{Y}^2$	m	$MSR = \frac{SSR}{m}$
ERROR	$SSE = Y'Y - b'X'Y$	n-m-1	$MSE = \frac{SSE}{n-m+1}$
TOTAL	$SSTO = Y'Y - n\bar{Y}^2$	n-1	

Coefficient of Multiple Determination

The coefficient of multiple determination, denoted by R^2, is defined as follows:

$$R^2 = \frac{SSR}{SSTO} = 1 - \frac{SSE}{SSTO}\ . \tag{4.25}$$

It measures the proportionate reduction of total sum of squares variation in Y associated with the use of the set of X variables $X_1, \ldots\ldots, X_m$. The coefficient of multiple determination R^2 reduces to the coefficient of simple determination r^2 (simple regression) when $m = 1$; that is, when one independent variable is in the model (equation 3.8). Thus, for R^2 we have

$$0 \leq R^2 \leq 1 . \qquad (4.26)$$

R^2 assumes the value of 0 when all $b_k = 0$ $(k = 1, \ldots\ldots, m)$. R^2 takes on the value 1 when all observations fall directly on the fitted response surface; that is, when $Y_i = \hat{Y}_i$ for all i.

<u>Coefficient of Multiple Correlation</u>

The coefficient of multiple correlation R is the positive square root of R^2:

$$R = \sqrt{R^2} . \qquad (4.27)$$

<u>Inferences About Regression Parameters</u>

The least squares estimators in b are unbiased:

$$E(b) = B . \qquad (4.28)$$

The variance-covariance matrix V(b):

$$V(b) = \begin{bmatrix} V(b_o) & C(b_o b_1) & \cdots & C(b_o, b_m) \\ C(b_1, b_o) & V(b_1) & \cdots & C(b_1, b_m) \\ \vdots & \vdots & \ddots & \vdots \\ C(b_m, b_o) & C(b_m, b_1) & & V(b_m) \end{bmatrix} \tag{4.29}$$

is given by

$$V(b) = \sigma^2(X'X)^{-1} \tag{4.31}$$

From $S^2(b)$, one can obtain $S^2(b_o)$, $S^2(b_1)$ or whatever other variance is needed or any needed covariances.

Weighted Least Squares

Draper and Smith (26) state that it sometimes happens that some of the observations used in a regression analysis are "less reliable" than others. What this usually means is that the variances of the observations are not equal; in other words, the matrix $V(\varepsilon)$ is not of the form $I\sigma^2$ but is diagonal with unequal diagonel elements. It may also happen, in some problems, that the off diagonal elements of $V(\varepsilon)$ are not zero; that is, that the observations are correlated.

When either or both of these events occur, the ordinary least squares estimation formula

$$b = (X'X)^{-1} X'Y \tag{4.33}$$

does not apply and it is necessary to amend the procedures for obtaining estimates. The basic idea is to transform the observations Y to other variables Z which do appear to satisfy the usual tentative assumptions [that $Z = QB + f$, $E(f) = 0$, $V(f) = I\sigma^2$, and for F-test and confidence intervals to be valid, that $f \sim N(0, I\sigma^2)$] and then to apply the usual (unweighted) analysis to the variables so obtained. The estimates can then be re-expressed in terms of the original variables Y. One shall describe how the usual regression procedures are changed. Suppose the model under consideration is

$$Y = XB + \varepsilon \tag{4.34}$$

where

$$E(\varepsilon) = 0, \ (V(\varepsilon) = V\ ^2, \text{ and } \varepsilon \sim N(0, V\sigma^2) \quad (4.35$$

It can be shown that for V non-singular it is possible to find a unique non-singular symmetric matrix P such that

$$P'P = PP = P^2 = V \tag{4.36}$$

Then let

$$f = P^{-1}\varepsilon, \text{ so that } E(f) = 0 \tag{4.37}$$

Now it is a fact that, if f is a vector random variable such that $E(f) = 0$, then $E(ff') = V(f)$ where the expectation is taken separately for every term in the square nxn matrix ff'. Thus

$$\begin{aligned} V(f) = E(ff') &= E(P^{-1}\varepsilon\varepsilon'P^{-1}) \ [\text{since } (P^{-1})' = P^{-1})] \\ &= P^{-1}E(\varepsilon\varepsilon')P^{-1} \\ &= P^{-1}PPP^{-1}\sigma^2 \ [\text{since } E(\varepsilon\varepsilon') = \sigma^2 V = \sigma^2 PP] \\ &= I\sigma^2 \end{aligned} \tag{4.38}$$

It is also true that f is normally distributed, since the element of f consists of linear combinations of the elements of ε which were normally distributed.

Therefore, if equation (4.34) is multiplied by P^{-1}, a new model is obtained:

$$P^{-1}Y = P^{-1}XB + P^{-1}\varepsilon \tag{4.39}$$

or

$$Z = QB + f \tag{4.40}$$

with an obvious notation. It is now clear that one can apply basic least squares theory to equation (4.40), since $E(f) = 0$ and $V(f) = I\sigma^2$. The residual sum of squares is

$$f'f = \varepsilon'V^{-1}\varepsilon = (Y-XB)'V^{-1}(Y - YB). \tag{4.41}$$

The normal equations $Q'Qb = Q'Z$ become

$$X'V^{-1}XB = X'V^{-1}Y \tag{4.42}$$

with solution

$$b = (X'V^{-1}X)^{-1}X'V^{-1}Y \tag{4.43}$$

when the matrix $(X'V^{-1}X)$ is nonsingular. The regression sum of squares is

$$b'Q'Z = Y'V^{-1}X(X'V^{-1}X)^{-1}X'V^{-1}Y \tag{4.44}$$

and the total sum of squares is

$$Z'Z = Y'V^{-1}Y. \tag{4.45}$$

The difference between equations (4.34) and (4.37) provides the residual sum of squares. The sum of squares due to the mean is $(\Sigma Z_i)^2/n$ where Z_i is the i^{th} element in the vector Z. The variance-covariance matrix of b is

$$V(b) = (Q'Q)^{-1}\sigma^2 = (X'V^{-1}X)^{-1}\sigma^2. \tag{4.46}$$

A joint confidence region for all of the parameters can be obtained from

$$(b-B)'Q'Q(b-B) = \left[\frac{p}{n-p}\right](Z'Z-b'Q'Z)F(p,n-p\ ,\ 1-\alpha) \tag{4.47}$$

after substituting from equations (4.44) and (4.45) and setting $Q = P^{-1}X$, if so desired.

The simplest application of weighted least squares occurs when the observations are independent but have different variances so that

$$V\sigma^2 = \begin{bmatrix} \sigma_1^2 & & & 0 \\ & \sigma_2^2 & & \\ & & \ddots & \\ 0 & & & \sigma_n^2 \end{bmatrix} \tag{4.48}$$

where some of the σ_i^2 may be equal.

In a practical problem, it is often difficult to obtain specific information on the form of V at first. For this reason, it is sometimes necessary to make the (known to be erroneous) assumption V = 0 and then attempt to discover something about the form of V by examining the residuals from the regression analysis.

If a weighted least squares analysis were called for but an ordinary least squares analysis were performed, the estimates obtained would still be unbiased but would not have minimum variance, since the minimum variance estimates are obtained from the correct weighted least squares analysis.

If standard least squares is used, then the estimates are obtained from

$$b_o = (X'X)^{-1}X'Y \text{ and}$$

$$E(b_o) = (X'X)^{-1}X'XB = B \tag{4.49}$$

but

$$V(b_o) = (X'X)^{-1}X' \left[V(Y)\right] X(X'X)^{-1} \tag{4.50}$$

$$= (X'X)^{-1}X'VX(X'X)^{-1}\sigma^2 \tag{4.51}$$

If the correct analysis is performed using equation (4.46), then

$$V(b) = (X'V^{-1}X)^{-1}\sigma^2 \tag{4.52}$$

and, in general, elements of this matrix would provide smaller variances both for individual coefficients and for linear functions of the coefficients.

An Example of Weighted Least Squares

A fit of the following model is desired. Suppose one wishes to fit the model

$$E(Y) = BX \tag{4.53}$$

Suppose that

$$V\sigma^2 = V(Y) = \begin{bmatrix} 1/W_1 & & & 0 \\ & 1/W_2 & & \\ 0 & & \ddots & \\ & & & 1/W_n \end{bmatrix} \sigma^2 \tag{4.54}$$

where the W's are weights to be specified. This means that

$$V^{-1} = \begin{bmatrix} W_1 & & & \\ & W_2 & & 0 \\ & 0 & \ddots & \\ & & & W_n \end{bmatrix} \tag{4.55}$$

Applying the general results above, one finds after reduction that

$$b = \frac{\Sigma W_i X_i Y_i}{\Sigma W_i X_i^2} \tag{4.56}$$

where all summations are from $i = 1, 2, \ldots\ldots, n$.

Case 1. Suppose $\sigma_i^2 = V(Y_i) = kX_i$--that is, variance of Y_i is proportional to the size of the corresponding X_i, then $W_i = \sigma^2/kX_i$. Hence,

$$b = \frac{\Sigma Y_i}{\Sigma X_i} = \frac{\bar{Y}}{\bar{X}} \tag{4.57}$$

Thus, if the variance of Y_i is proportional to X_i, the best estimate of the regression coefficient is the mean of Y_i, divided by the mean of X_i. In addition,

$$V(b) = \frac{\sigma^2}{\Sigma W_i X_i^2} = \frac{k}{\Sigma X_i} \tag{4.58}$$

Case 2. Suppose $\sigma_i^2 = V(Y_i) = kX_i^2$--that is, the variance of Y_i is proportional to the square of the corresponding X_i--then $W_i = \sigma^2/kX_i^2$. Hence,

$$b = \frac{\Sigma(Y_i/X_i)}{\Sigma 1} \tag{4.59}$$

$$= \frac{\Sigma(Y_i/X_i)}{n} \, . \tag{4.60}$$

Thus, if the variance of the Y_i is proportional to X_i^2, the best estimate of the regression coefficient is the average of the n slopes obtained, one from each pair of observations Y_i/X_i. Also

$$V(b) = \frac{\sigma^2}{\Sigma W_i X_i^2} = \frac{k}{n} \tag{4.61}$$

Application of Multiple Regression and Weighted Least Squares

In this study, a multiple regression technique will be used as a way to find the peak flow for selected recurrence intervals of 2, 5, 10, 25, 50, and 100 years.

Annual peak flow of the drainage area will be expressed as a function of drainage basin characteristics and climatic conditions by using multiple regression analysis as an equation of the form

$$Y = F(X_1, X_2, X_3, \ldots\ldots X_n)$$

where

Y = dependent variable (Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, and Q_{100})

F = the function, for example, linear function or logarithmic function

$X_1, X_2, X_3, \ldots\ldots X_n$ = drainage basin characteristics and climatic conditions

The weighted least squares will be used to adjust the best fit of the equation when the residuals have different variances.

Analysis of the model and results of flood flow frequency in the form of multiple regression model will be developed in the next chapter.

CHAPTER V

STATISTICAL MODEL AND ANALYSIS OF FLOOD FREQUENCIES

Flood Records

Systematic collection of flood records (peak stage and discharge) began in northeastern Thailand between 1950 and 1961 (28)(29)(30)(31). During this period, many continuous record gaging stations were installed throughout northeastern Thailand to define the flow characteristics of streams. Some streams have records prior to 1960, but these records are generally fragmentary and, in most cases, only stream stages are available. Generally, the records prior to 1960 are for the large basins only. Since the 1962-1974 era, many additional stream flow stations have been installed.

The most notable addition to the collection of flood records was begun in the early 1960s by the Committee of the Lower Mekong Basin. The Committee's contribution represents a part of a comprehensive plan for ultimate development of the water resources of that part of the Mekong River basin lying in the riparian countries, under the sponsorship of the United Nations (32). During that time, about 20 stream sites were instrumented for the collection of flood data. The number of sites has been increased, and some have been discontinued because hydraulic structures have been built, or because the site was unusable, but more than 40 sites are still in operation at this time.

The flood frequency analysis for streams of northeastern Thailand, which is presented in the following section of this thesis, is based on flood records through 1974 at 40 sites. For this analysis, the only records used were those with at least five years of flood peak data. A summary of the distribution of data and average length of record per station is as follows:

TABLE II

SUMMARY OF THE DISTRIBUTION OF DATA AND AVERAGE LENGTH OF RECORD PER STATION

Drainage Area sq. km.	No. of Stations	Average Length of Record, Years
1- 100	1	9
100- 1,000	11	9
1,000- 10,000	18	11
10,000-100,000	6	15
100,000-200,000	2	13

Appendix B of this report contains a listing of all flood records with at least five annual peaks for gaging stations in northeastern Thailand. A total of 38 stations is included.

Flood Frequency Relations

The relation of flood peak magnitude to probability of occurrence, or recurrence interval, is generally referred to as a flood frequency relation. Probability of occurrence is the percent chance of a given flood magnitude being exceeded in any one year. Recurrence interval is the reciprocal of probability of occurrence. It is emphasized that a recurrence interval is an average interval. For instance, a flood having a probability of occurrence of two percent has a recurrence interval of 50 years. This does not mean that each 50 years this flood will be exceeded, but that it will be exceeded on the average of once every 50 years. In fact, it may be exceeded in successive years, or even twice in the same year.

The probability of a flood of given magnitude occurring in a given period of time can also be calculated. For instance, there is a 64 percent chance that the 50-year flood will be exceeded at least once in a given 50-year period. Table III lists the probabilities of experiencing a flood of selected recurrence interval during various periods of time.

Log Pearson Type III Distribution for Northeastern Thailand Streams

The flood frequency relation for a stream where gaging station records are available can be defined by fitting the array of annual peak discharges (largest instantaneous discharge for each year) to a theoretical distribution. The U. S. Water Resources Council (23) had recommended a uniform technique for determining flood flow frequencies by fitting the logarithms of the annual peak discharges to a Pearson

Type III distribution.

TABLE III

PROBABILITY THAT AN EVENT OF GIVEN RECURRENCE INTERVAL WILL BE EXCEEDED AT LEAST ONCE DURING PERIODS OF VARIOUS LENGTHS

Recurrence Interval (Years)	Probability, in percent, for indicated period, in years			
	2	10	50	100
2	97	99.9	a	a
10	41	65	99.5	a
50	10	18	64	87
100	5	10	39	63

a = probability greater than 99.9 but less than 100 percent

The details of the Log-Pearson Type III calculations are described in the Water Resources Council Bulletin 15 (23).

The computer program used in this research was furnished by the U. S. Geological Survey (24).

Flood Frequency at Ungaged Sites on Streams of Northeastern Thailand

Flood frequency relation can be estimated for ungaged sites for northeastern Thailand through the use of the equations and graphs presented in this section, and for the practical engineering use in the section on Engineering Application. The equations were developed by relating the 2-, 5-, 10-, 25-, 50-, and 100-year floods to six basin and climatic characteristics.

The following parameters are defined for use in this study:

1) Drainage Area (DA). The contributing drainage area of the basin measured, in square kilometers (km^2), measured from the topographic map of northeastern Thailand (34) and checked with the hydrologic report of the Royal Irrigation Department and National Energy Authority of Thailand (28)(29)(30)(31).

2) Annual Precipitation (ANRAIN). The mean annual precipitation for the basin, in centimeters (cm), during the period 1951-1971 (29)(48) (see Figure 9).

3) Annual Evaporation (EVAP). The mean annual evaporation for the basin, in centimeters, during the period 1954-1970 (14)(29)(see Appendix A).

4) Average Elevation of the Basin (EL). For this study, the mean basin elevation, in thousands of meters above sea level, was used. This parameter was evaluated by laying grid over a topographic map (34) of each basin and determining the mean of the elevations under each grid intersection. The grid spacing was selected so as to provide no less than five intersections within the basin boundary.

5) Surface Storage (SS). The index of each basin's surface storage was computed as the percentage of total drainage area occupied by lakes, ponds, rice paddies, and swamps. To avoid difficulties associated with the use of zeros in the regression analysis when logarithms were taken, all values of percent of drainage area in lakes, ponds, and swamps were increased by values of one percent.

6) Main-channel Length (LENGTH). This is a variable indicating the basin shape in conjunction with the basin area. Values of main-channel length, in kilometers, were measured from a topographic map of the Royal Thai Army (34).

The parameter proving most significant for this study was found to be drainage area sizes by using the statistical package called "Stepwise Regression" from the Statistic Analysis System Package Program (46).

In this stepwise regression procedure, several regressions are computed, the first one including all six basin and climatic characteristics: drainage area, annual precipitation, annual evaporation, average elevation of the basin, surface storage, and main channel length. A "backward elimination" computer program will make the first computation, eliminate the least significant variable, and recompute the regression, then continue the elimination process until only the drainage area remains.

A preferable approach is to select carefully a few variables having clear physical relationships to the flood peak, and to compute the regression equation and check regression coefficients for significance. A computer program called "forward selection" regression will select the most highly related variable and test it for significance, then select the next most highly related variable, compute the regression on the two and test for significance. It then proceeds similarly until all of the significant variables are included in the regression. The only one highly significant in this procedure is the drainage area.

Table IV shows the linear model equations. Table V shows the logarithmic model equations. Each equation contains six variables

TABLE IV

LINEAR MODEL EQUATIONS PEAK FLOW RELATED TO SIX VARIABLES

Model Forms	R^2	Variable	Observed Significant Level > |t|
Q_2 = -247.07 + 0.03 DA + 0.19 ANRAIN - 1.39 LENGTH + 0.15 EVAP - 0.3155SS - 0.01 EL	0.952	DA	0.0001*
		ANRAIN	0.1069
		LENGTH	0.1516
		EVAP	0.5387
		SS	0.7773
		EL	0.9319
Q_5 = 52.27 + 0.04 DA - 2.80 LENGTH - 0.08 EL + 0.08 ANRAIN + 0.12 EVAP	0.945	DA	0.0001*
		LENGTH	0.0559
		EL	0.6739
		ANRAIN	0.6375
		EVAP	0.6862
		SS	0.7082
Q_{10} = 360.710 + 0.04 DA - 3.77 LENGTH + 1.45 SS - 0.14 EL + 0.06 EVAP	0.925	DA	0.0001*
		LENGTH	0.0594
		SS	0.5407
		EL	0.5936
		EVAP	0.8720
		ANRAIN	0.9099
Q_{25} = 901.73 + 0.05 DA - 4.96 LENGTH + 2.57 SS - 0.22 ANRAIN - 0.25 EL - 0.05 EVAP	0.875	DA	0.0001*
		LENGTH	0.1092
		SS	0.5145
		ANRAIN	0.5507
		EL	0.5634
		EVAP	0.9377

TABLE IV (Continued)

Model Forms	R^2	Variable	Observed Significant Level $> \lvert t \rvert$
Q_{50} = 1448.97 + 0.06 DA - 5.71 LENGTH + 3.38 SS - 0.43 ANRAIN - 0.35 EL - 0.15 EVAP	.809	DA	0.0001*
		LENGTH	0.1877
		SS	0.5137
		ANRAIN	0.5921
		EL	0.5648
		EVAP	0.8548
Q_{100} = 2135.24 + 0.06 DA - 6.28 LENGTH + 4.18 SS - 0.70 ANRAIN - 0.46 EL - 0.28 EVAP	.716	DA	0.0001*
		LENGTH	0.3027
		SS	0.5637
		ANRAIN	0.6681
		EL	0.5859
		EVAP	0.8134

*denotes the significant variable

TABLE V

LOG MODEL EQUATIONS PEAK FLOW RELATED TO SIX VARIABLES

Model Forms	R^2	Variable	Observed Significant Level $> \|t\|$
$\text{Log } Q_2 = -5.77 + 0.51 \log DA + 1.18 \log ANRAIN + 0.22 \log EL + 0.59 \log EVAP - 0.008 \log SS - 0.004 \log LENGTH$	0.811	log DA	0.0001*
		log ANRAIN	0.0564
		log EL	0.5365
		log EVAP	0.5937
		log SS	0.9557
		log LENGTH	0.9795
$\text{Log } Q_5 = -2.42 + 0.55 \log DA + 0.61 \log EVAP + 0.29 \log ANRAIN + 0.11 \log EL + 0.04 \log LENGTH + 0.03 \log SS$	0.800	log DA	0.0001*
		log EVAP	0.6057
		log ANRAIN	0.6430
		log EL	0.7094
		log LENGTH	0.8309
		log SS	0.8358
$\text{Log } Q_{10} = -0.96 + 0.51 \log DA + 0.61 \log EVAP + 0.07 \log LENGTH - 0.12 \log ANRAIN + 0.05 \log SS + 0.08 \log EL$	0.777	log DA	0.0001*
		log EVAP	0.5861
		log LENGTH	0.7330
		log ANRAIN	0.8461
		log SS	0.7686
		log EL	0.7983
$\text{Log } Q_{25} = 0.428 + 0.48 \log DA\ 0.62 \log EVAP - 0.52 \log ANRAIN + 0.11 \log LENGTH + 0.063 \log SS + 0.061 \log EL$	.734	log DA	0.0001*
		log EVAP	0.5454
		log ANRAIN	0.5243
		log LENGTH	0.6370
		log SS	0.7195
		log EL	0.8493

TABLE V (Continued)

Model Forms	R^2	Variable	Observed Significant Level > |t|
Log Q_{50} = 1.24 + 0.46 log DA - 0.75 log ANRAIN + 0.63 log EVAP + 0.13 log LENGTH + 0.07 log SS + 0.06 log EL	0.691	log DA	0.0004*
		log EVAP	0.6654
		log ANRAIN	0.5137
		log LENGTH	0.5993
		log SS	0.7051
		log EL	0.8688
Log Q_{100} = 1.85 + 0.441 log DA - 0.96 log ANRAIN + 0.65 log EVAP + 0.16 log LENGTH + 0.084 log SS + 0.07 log EL	0.648	log DA	0.0011*
		log ANRAIN	0.2624
		log EVAP	0.5123
		log LENGTH	0.5604
		log SS	0.6924
		log EL	0.8565

*denotes the significant variable

related to drainage basin characteristics and climatic conditions. The R^2 (coefficient of determination) for each model and probability of getting a greater students t distribution value (observe significant level more than .05) for each variable is indicated. These two tables show that the drainage area is the most significant variable of the models. The theory concerned in this stepwise regression is shown in the section of a multiple regression technique, Chapter IV. For the equations containing 5, 4, 3, and 2 independent variables, see Appendix C. Again, the drainage area was the most significant variable in all of these analyses.

Relation of Flood Peaks of Selected Recurrence Interval and Drainage Area

Standard simple linear regression techniques were used to determine the relation of the drainage area to flood peaks of selected recurrence intervals. The model used in the regression analysis is of the form

$$Q_T = a + bDA \tag{5.1}$$

and

$$Q_T = aDA^b \tag{5.2}$$

where

Q_T = peak discharge, in cubic meters per second (m^3/sec) for recurrence interval T years

a = regression constant

b = regression coefficient

DA = drainage area square kilometers (km^2).

The weighted least squares model given in equation (4.54) was used with W_T being the variance of the Q_T values as derived by Hardison (36). This weight function was used in an attempt to minimize the effect of the "less reliable" basin for this purpose.

$$W_T = N/(1 + 2RBK_T + B^2K_T + B_2K_T^2/2) \tag{5.3}$$

where

N = number of years

R = correlation coefficient of the sample means and the sample standard deviations given by Kendall (35). Values of R for use in this equation have been determined by sampling to be about 0.3 for G of 0.5, 0.5 for G of 1.0, and 0.65 for G of 1.5. For negative skew coefficients, values of R are positive in sign to those for the corresponding positive skew coefficient

B = $(0.75G^2 + 1)$ varies with G

G = coefficient of skewness for each stream basin

K_T = from Table I, from "A Uniform Technique for Determing Flood Flow Frequencies" (23).

The coefficients of K_T, G vary in both linear model equation (5.1) and exponential model equation (5.2). The coefficients b were all significant at the five percent level of significance. The linear regression model and log transform model which were presented in Tables VI and VII, show the standard error and the R^2. The predicted and observed values of Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, and Q_{100} were shown in Tables

TABLE VI

WEIGHTED LINEAR AND LOG TRANSFORM MODEL OF 36 BASINS

Variable	a	b	S^2	R^2	Form of Mathematical Model	Model Name
Q_2	128.34	0.02	421.92	0.910	$Q_2 = 128.33 + 0.02DA$	B2
Q_5	218.17	0.03	362.48	0.932	$Q_5 = 218.16 + 0.03DA$	B5
Q_{10}	265.61	0.03	427.54	0.906	$Q_{10} = 265.61 + 0.03DA$	B10
Q_{25}	289.21	0.04	540.59	0.852	$Q_{25} = 289.21 + 0.04DA$	B25
Q_{50}	330.81	0.04	651.88	0.798	$Q_{50} = 330.81 + 0.04DA$	B50
Q_{100}	418.14	0.05	783.15	0.738	$Q_{100} = 418.13 + 0.05DA$	B100
$\log Q_2$	0.44	0.54	0.79	0.993	$Q_2 = 2.74DA^{0.54}$	AB2L
$\log Q_5$	0.69	0.52	0.44	0.994	$Q_5 = 4.94DA^{0.52}$	AB5L
$\log Q_{10}$	0.74	0.53	0.37	0.994	$Q_{10} = 5.54DA^{0.53}$	AB10L
$\log Q_{25}$	0.79	0.54	0.32	0.994	$Q_{25} = 6.18DA^{0.54}$	AB25L
$\log Q_{50}$	0.82	0.54	0.31	0.993	$Q_{50} = 6.61DA^{0.54}$	AB50L
$\log Q_{100}$	085	0.54	0.30	0.993	$Q_{100} = 7.02DA^{0.54}$	AB100L

TABLE VII

WEIGHTED LINEAR AND LOG TRANSFORM MODEL OF 38 BASINS

Variable	a	b	S^2	R^2	Form of Mathematical Model	Model Name
Q_2	88.05	0.025	556.72	0.972	$Q_2 = 88.05 + 0.02DA$	M2
Q_5	168.86	0.03	469.41	0.974	$Q_5 = 168.86 + 0.03DA$	M5
Q_{10}	222.24	0.04	501.25	0.963	$Q_{10} = 222.24 + 0.04DA$	M10
Q_{25}	260.04	0.04	591.31	0.939	$Q_{25} = 260.04 + 0.04DA$	M25
Q_{50}	309.914	0.05	692.06	0.909	$Q_{50} = 309.01 + 0.05DA$	M50
Q_{100}	396.46	0.05	815.12	0.87	$Q_{100} = 396.46 + 0.05DA$	M100
log Q_2	0.25	0.59	0.809	0.993	$Q_2 = 1.79DA^{0.59}$	AM2L
log Q_5	0.55	0.568	0.454	0.995	$Q_5 = 3.51DA^{0.57}$	AM5L
log Q_{10}	0.63	0.566	0.371	0.995	$Q_{10} = 4.23DA^{0.57}$	AM10L
log Q_{25}	0.701	0.565	0.321	0.994	$Q_{25} = 5.02DA^{0.566}$	AM25L
log Q_{50}	0.741	0.565	0.302	0.994	$Q_{50} = 5.52DA^{0.56}$	AM50L
$\log_{100}$	0.776	0.564	0.292	0.993	$Q_{100} = 5.96DA^{0.56}$	AM100L

TABLE VIII

TABLE SHOWS SEVERAL PREDICTED MODELS COMPARED WITH OBSERVED MODEL Q_2

OBS	NO	Q2	M2	AM2L	B2	AB2L	DA
1	1	1013	1157.48	1041.82s	907.201	845.112	43100
2	2	39	98.00	64.03s	135.583	68.623	401
3	3	110	105.49s	89.49	141.040	92.758	703
4	4	383	189.53	255.78s	202.247	238.719	4090
5	5	238	118.81	125.54	150.744s	125.793	1240
6	6	438	203.43	276.12s	212.367	255.743	4650
7	7	130	114.60	114.97	147.672	116.220s	1070
8	8	255	121.30	131.48	152.551s	131.141	1340
9	9	148	105.46	89.42	141.022s	92.687	702
10	10	307	170.92	226.67s	188.694	214.121	3340
11	11	421	139.16	169.92s	165.563	165.194	2060
12	14	132	146.60s	184.27	170.984	177.701	2360
13	15	27	89.56	20.83	129.438	24.972s	61
14	16	64	96.21	56.90	134.282	61.706s	329
15	17	201	123.03	135.53	153.816s	134.775	1410
16	18	464	795.21	814.08	643.363s	676.839	28500
17	20	153	101.69	77.31	138.275s	81.307	550
18	21	140	120.48	129.54s	151.955	129.397	1307
19	22	76	102.36	79.55s	138.763	83.426	577
20	23	298	139.19	169.97s	165.581	165.237	2061
21	24	285	160.15	208.62s	180.851	198.705	2906
22	25	226	163.13	213.71s	183.019	203.068	3026
23	26	173	108.44	98.24	143.191s	100.881	822
24	27	237	207.15	281.40	215.078s	260.139	4800
25	28	599	827.89	836.31	667.163s	693.453	29817
26	29	212	225.56s	306.58	228.486	281.006	5542
27	30	38	120.10s	128.65	151.684	128.598	1292
28	32	653	827.54	836.08	666.910s	693.278	29803
29	33	404	414.86s	513.75	366.351	447.231	13171
30	34	73	117.80s	123.04	150.003	123.543	1199
31	35	66	102.09	78.64s	138.564	82.569	566
32	36	61	109.76	101.97s	144.148	104.322	875
33	37	117	415.15	514.03	366.568s	447.449	13183
34	38	42	99.11	68.22s	136.396	72.655	446
35	39	41	93.88	46.56s	132.583	51.509	235
36	40	158	115.76	117.95	148.522s	118.933	1117
37	12	2697	2668.59s	1761.70			104000
38	19	3441	2991.16s	1889.89			117000

Subscript s Denotes the Prediction Closest to Actual Data Among the Four Models Used

Q2 = Peak Flow Recurrence Interval of 2 Years (Appendix B)

M2 = Linear Model of 38 Basins (Table VI)

AM2L = Logarithmic Model of 38 Basins (Table VI)

B2 = Linear Model of 36 Basins (Table VII)

AB2L = Log Model of 36 Basins (Table VII)

NO = Number of Drainage Basins Corresponding to Appendix B

DA = Drainage Area in Square Kilometers

TABLE IX

TABLE SHOWS SEVERAL PREDICTED MODELS COMPARED WITH OBSERVED MODEL Q_5

OBS	NO	Q5	M5	AM5L	B5	AB5L	DA
1	1	1293	1597.04	1519.87	1362.86	1288.32ı	43100
2	2	54	182.14	106.19ı	228.82	112.40	401
3	3	156	192.15	146.15	236.84	150.62ı	703
4	4	572	304.39	398.02ı	326.79	377.31	4090
5	5	471	209.95	201.85	251.10ı	202.50	1240
6	6	526	322.94	428.17ı	341.67	403.42	4650
7	7	178	204.31	185.60ı	246.58	187.51	1070
8	8	383	213.26	210.95	253.76ı	210.85	1340
9	9	177	192.12ı	146.03	236.81	150.51	702
10	10	498	279.53	354.69ı	306.87	339.48	3340
11	11	541	237.12	269.43ı	272.88	263.86	2060
12	14	173	247.06ı	291.10	280.85	283.25	2360
13	15	40	170.88	36.37ı	219.79	42.10	61
14	16	114	179.76	94.88	226.90	101.38ı	329
15	17	298	215.58	217.15	255.61ı	216.53	1410
16	18	710	1113.25	1201.17	975.10ı	1038.37	28500
17	20	229	187.08	127.10	232.77ı	132.53	550
18	21	230	212.17ı	207.98	252.88	208.13	1307
19	22	106	187.98	130.61ı	233.49	135.88	577
20	23	384	237.15	269.50	272.90ı	263.93	2061
21	24	543	265.15	327.69ı	295.35	315.71	2906
22	25	482	269.13	335.32ı	298.53	322.45	3026
23	26	322	196.10	159.75	240.00ı	163.42	822
24	27	543	327.91	435.97ı	345.65	410.15	4800
25	28	936	1156.89	1232.44	1010.07ı	1063.12	29817
26	29	442	352.50	473.13	365.36	442.08ı	5542
27	30	84	211.67	206.62ı	252.48	206.88	1292
28	32	1154	1156.42ı	1232.11	1009.70	1062.86	29803
29	33	941	605.30	774.24ı	567.97	694.29	13171
30	34	79	208.59	198.02ı	250.01	198.98	1199
31	35	131	187.61	129.19ı	233.20	134.53	566
32	36	129	197.85	165.53ı	241.41	168.83	875
33	37	183	605.70	774.64	568.29ı	694.62	13183
34	38	116	183.64	112.81	230.01	118.81ı	446
35	39	70	176.64	78.35	224.41ı	85.06	235
36	40	313	205.87	190.20	247.83ı	191.76	1117
37	12	3586	3615.05ı	2508.79			104000
38	19	4951	4045.83ı	2682.67			117000

Subscript ı Denotes the Prediction Closest to Actual Data Among the Four Models Used

Q5 = Peak Flow Recurrence Interval of 5 Years (Appendix B)

M5 = Linear Model of 38 Basins (Table VI)

AM5L = Logarithmic Model of 38 Basins (Table VI)

B5 = Linear Model of 36 Basins (Table VII)

AB5L = Log Model of 36 Basins (Table VII)

NO = Number of Drainage Basins Corresponding to Appendix B

DA = Drainage Area in Square Kilometers

TABLE X

TABLE SHOWS SEVERAL PREDICTED MODELS COMPARED WITH OBSERVED MODEL Q_{10}

OBS	NO	Q10	M10	AM10L	B10	AB10L	DA
1	1	1473	1855.59	1797.83	1664.10	1576.97$_h$	43100
2	2	64	237.44	126.81$_h$	278.63	132.43	401
3	3	196	248.88	174.33	288.42	178.29$_h$	703
4	4	712	377.24	473.07$_h$	398.32	453.06	4090
5	5	743	269.23	240.49	305.85$_h$	240.80	1240
6	6	586	398.46	508.77$_h$	416.49	484.92	4650
7	7	195	262.79	221.20$_h$	300.33	222.71	1070
8	8	473	273.02	251.30	309.09$_h$	250.90	1340
9	9	192	248.84	174.19	288.39	178.15$_h$	702
10	10	677	348.82	421.75$_h$	373.99	406.97	3340
11	11	636	300.31	320.68	332.46$_h$	315.07	2060
12	14	196	311.68$_h$	346.37	342.19	338.59	2360
13	15	48	224.55	43.60$_h$	267.59	48.85	61
14	16	153	234.71	113.35	276.29	119.26$_h$	329
15	17	342	275.67	258.66	311.37$_h$	257.76	1410
16	18	844	1302.30	1422.04	1190.36$_h$	1266.74	28500
17	20	278	243.08	151.68	283.46$_h$	156.56	550
18	21	288	271.77$_h$	247.77	308.02	247.61	1307
19	22	130	244.11	155.86$_h$	284.34	160.58	577
20	23	432	300.35	320.76	332.49$_h$	315.15	2061
21	24	827	332.37	389.74$_h$	359.91	378.05	2906
22	25	647	336.92	398.79$_h$	363.80	386.24	3026
23	26	403	253.39	190.49	292.29$_h$	193.68	822
24	27	785	404.14	518.01$_h$	421.36	493.15	4800
25	28	1119	1352.21	1458.93	1233.10$_h$	1297.41	29817
26	29	641	432.26	561.99$_h$	445.44	532.15	5542
27	30	126	271.20	246.15	307.54	246.10$_h$	1292
28	32	1481	1351.68	1458.54$_h$	1232.64	1297.09	29803
29	33	1505	721.38	918.05$_h$	692.98	841.68	13171
30	34	81	267.68	235.95$_h$	304.52	236.55	1199
31	35	196	243.69	154.17	283.98	158.95$_h$	566
32	36	171	255.40	197.36$_h$	294.01	200.20	875
33	37	241	721.83$_h$	918.52	693.37	842.09	13183
34	38	189	239.14	134.69	280.09	140.11$_h$	446
35	39	91	231.15	93.66$_h$	273.24	99.79	235
36	40	452	264.57	226.66	301.86$_h$	227.84	1117
37	12	4074	4163.50$_h$	2962.30			104000
38	19	5930	4656.15$_h$	3166.86			117000

h

Subscript h Denotes the Prediction Closest to Actual Data Among the Four Models Used

Q10 = Peak Flow Recurrence Interval of 10 Years (Appendix B)

M10 = Linear Model of 38 Basins (Table VI)

AM10L = Logarithmic Model of 38 Basins (Table VI)

NO = Number of Drainage Basins Corresponding to Appendix B

B10 = Linear Model of 36 Basins (Table XII)

DA = Drainage Area in Square Kilometers

TABLE XI

TABLE SHOWS SEVERAL PREDICTED MODELS COMPARED WITH OBSERVED MODEL Q_{25}

OBS	NO	Q25	M25	AM25L	B25	AB25L	DA
1	1	1696	2140.49	2107.12	2014.95	1900.21$_o$	43100
2	2	78	277.53	149.29	340.99	154.33$_o$	401
3	3	259	290.71$_o$	205.12	352.83	208.61	703
4	4	908	438.49	555.71$_o$	485.61	536.82	4090
5	5	1303	314.14	282.82	373.88$_o$	282.89	1240
6	6	664	462.92	597.57$_o$	507.57	575.10	4650
7	7	206	306.72	260.18$_o$	367.22	261.37	1070
8	8	593	318.50	295.51	377.80$_o$	294.92	1340
9	9	207	290.67	204.96$_o$	352.79	208.45	702
10	10	978	405.76	495.52$_o$	456.21	481.51	3340
11	11	773	349.92	376.94	406.03$_o$	371.49	2060
12	14	222	363.01$_o$	407.09	417.79	399.62	2360
13	15	57	262.70	51.43	327.66	56.17$_o$	61
14	16	208	274.39$_o$	133.47	338.17	138.78	329
15	17	381	321.56	304.15	380.55$_o$	303.09	1410
16	18	982	1503.49	1667.34	1442.58$_o$	1521.88	28500
17	20	336	284.03	178.52	346.85$_o$	182.86	550
18	21	359	317.06	291.37	376.51$_o$	291.00	1307
19	22	164	285.21	183.43$_o$	347.89	187.62	577
20	23	486	349.96	377.04	406.07$_o$	371.59	2061
21	24	1391	386.83	457.98$_o$	439.20	446.84	2906
22	25	828	392.06	468.59$_o$	443.90	456.66	3026
23	26	480	295.90	224.11	357.50$_o$	226.87	822
24	27	1108	469.46	608.41$_o$	513.45	584.98	4800
25	28	1306	1560.95	1710.52	1494.21$_o$	1559.24	29817
26	29	942	501.84	659.97$_o$	542.54	631.90	5542
27	30	196	316.41	289.47	375.92	289.20$_o$	1292
28	32	1867	1560.34	1710.07$_o$	1493.66	1558.84	29803
29	33	2537	834.69	1077.21$_o$	841.62	1005.65	13171
30	34	84	312.35	277.49$_o$	372.28	277.83	1199
31	35	311	284.73$_o$	181.44	347.45	185.69	566
32	36	223	298.21	232.17$_o$	359.57	234.61	875
33	37	336	835.21$_o$	1077.76	842.09	1006.14	13183
34	38	305	279.50	158.55	342.76$_o$	163.40	446
35	39	122	270.29	110.33	334.48	115.85$_o$	235
36	40	671	308.77	266.58	369.06$_o$	267.47	1117
37	12	4597	4797.56$_o$	3468.99			104000
38	19	7143	5364.75$_o$	3708.12			117000

o

Subscript o Denotes the Prediction Closest to Actual Data Among the Four Models Used (DA = Drainage Area in Square Kilometers)

Q25 = Peak Flow Recurrence Interval of 25 Years (Appendix B)

M25 = Linear Model of 38 Basins (Table VI)

AM25L = Logarithmic Model of 38 Basins (Table VI)

B25 = Linear Model of 36 Basins (Table VII)

AB25L = Logarithmic Model of 36 Basins (Table VII)

NO = Number of Drainage Basins Corresponding to Appendix B

TABLE XII

TABLE SHOWS SEVERAL PREDICTED MODELS COMPARED WITH OBSERVED MODEL Q_{50}

OBS	NO	Q50	M50	AM50L	B50	AB50L	DA
1	1	1863	2341.11	2306.30	2250.54	2107.51e	43100
2	2	88	327.92	163.67e	388.57	168.40	401
3	3	317	342.16e	224.84	401.74	228.07	703
4	4	1067	501.85	608.75e	549.43	590.52	4090
5	5	1959	367.48	309.94	425.16e	309.90	1240
6	6	724	528.25	654.57e	573.85	632.91	4650
7	7	210	359.46	285.14e	417.74	286.17	1070
8	8	687	372.19	323.84	429.52e	323.16	1340
9	9	216	342.11	224.66e	401.69	227.90	702
10	10	1270	466.49	542.85e	516.73	529.30	3340
11	11	890	406.14	413.02	460.91e	407.68	2060
12	14	239	420.28e	446.03	474.00	438.75	2360
13	15	63	311.89	56.42e	373.74	60.89	61
14	16	254	324.53	146.34	385.43	151.33e	329
15	17	400	375.49e	333.30	432.57	332.18	1410
16	18	1064	1652.74	1825.22	1613.88e	1685.48	28500
17	20	378	334.95	195.70	395.07e	199.75	550
18	21	409	370.64e	319.31	428.08	318.84	1307
19	22	194	336.22	201.08e	396.24	204.99	577
20	23	520	406.19	413.13	460.96e	407.79	2061
21	24	2023	446.03	501.75e	497.80	490.96	2906
22	25	941	451.69	513.36e	503.04	501.81	3026
23	26	551	347.77	245.64	406.93e	248.18	822
24	27	1352	535.33	666.43e	580.40	643.86	4800
25	28	1418	1714.84	1872.45	1671.31e	1727.13	29817
26	29	1201	570.31	722.88e	612.75	695.85	5542
27	30	259	369.93	317.23	427.42	316.86e	1292
28	32	2130	1714.18	1871.96e	1670.70	1726.69	29803
29	33	3597	930.01	1179.53e	945.43	1110.76	13171
30	34	86	365.54	304.10e	423.37	304.32	1199
31	35	427	335.70	198.90	395.76e	202.87	566
32	36	260	350.27	254.47	409.24	256.70e	875
33	37	423	930.57e	1180.13	945.95	1111.31	13183
34	38	408	330.04	173.82	390.53e	178.36	446
35	39	148	320.09	120.98e	381.33	126.18	235
36	40	869	361.68	292.16	419.79e	292.90	1117
37	12	4931	5212.45e	3795.71			104000
38	19	8008	5825.38e	4057.19			117000

e

Subscript e Denotes the Prediction Closest to Actual Data Among the Four Models Used (DA = Drainage Area in Square Kilometers)

Q50 = Peak Flow Recurrence Interval of 50 Years (Appendix B)

M50 = Linear Model of 38 Basins (Table VI)

AM50L = Logarithmic Model of 38 Basins (Table VI)

B50 = Linear Model of 36 Basins (Table VII)

AB50L - Logarithmic Model of 36 Basins (Table VII)

NO = Number of Drainage Basins Corresponding to Appendix B

TABLE XIII

TABLE SHOWS SEVERAL PREDICTED MODELS COMPARED WITH OBSERVED MODEL Q_{100}

OBS	NO	Q100	M100	AM100L	B100	AB100L	DA
1	1	2023	2541.24	2474.85	2462.33	2280.93[a]	43100
2	2	98	416.42	176.29	437.16	180.83[a]	401
3	3	386	431.45[a]	242.07	451.48	245.14	703
4	4	1237	599.99	654.46[a]	612.12	636.58	4090
5	5	2914	458.17	333.54	476.95[a]	333.41	1240
6	6	786	627.86	703.66[a]	638.68	662.43	4650
7	7	211	449.71	306.88[a]	468.89	307.80	1070
8	8	783	463.15	348.47	481.69[a]	347.72	1340
9	9	223	431.40	241.87[a]	451.43	244.95	702
10	10	1633	562.67	583.71[a]	576.55	570.40	3340
11	11	1018	498.97	444.28	515.84[a]	438.97	2060
12	14	255	513.90	479.74	530.07	472.54[a]	2360
13	15	70	399.50	60.86[a]	421.03	65.18	61
14	16	302	412.84[a]	157.65	433.74	162.44	329
15	17	414	466.63[a]	358.64	485.01	357.45	1410
16	18	1133	1814.70	1959.25	1769.86[a]	1822.91	28500
17	20	417	423.83[a]	210.73	444.22	214.61	550
18	21	456	461.50[a]	343.60	480.13	343.05	1307
19	22	227	425.18	216.51	445.51	220.25[a]	577
20	23	552	499.02	444.40	515.89[a]	439.09	2061
21	24	2911	541.07	539.58	555.97[a]	528.95	2906
22	25	1035	547.05	552.05	561.66[a]	540.68	3026
23	26	552	437.37	264.42	457.13[a]	266.82	822
24	27	1593	635.32	716.39[a]	645.80	694.27	4800
25	28	1510	1880.24	2009.88	1832.33[a]	1868.09	29817
26	29	1490	672.25	776.98[a]	680.99	750.51	5542
27	30	333	460.76	341.37	479.42	340.91[a]	1292
28	32	2371	1879.54	2009.35[a]	1831.66	1867.61	29803
29	33	4966	1051.89	1266.92[a]	1042.83	1199.77	13171
30	34	87	456.13	327.26[a]	475.01	327.39	1199
31	35	576	424.63	214.17	444.98[a]	217.97	566
32	36	295	440.01	273.92[a]	459.64	276.01	875
33	37	528	1052.48	1267.58	1043.39[a]	1200.36	13183
34	38	523	418.66	187.21	439.29[a]	191.56	446
35	39	176	408.16	130.36	429.28	135.37[a]	235
36	40	1099	452.05	314.43	471.12[a]	315.06	1117
37	12	5226[a]	5571.78	4070.24			104000
38	19	8861[a]	6218.70	4350.22			117000

a.

Subscript a Denotes the Prediction Closest to Actual Data Among the Four Models Used (DA = Drainage Area in Square Kilometers)

Q100 = Peak Flow Recurrence Interval of 100 Years (Appendix B)

M100 = Linear Model of 38 Basins (Table VI)

AM100L = Logarithmic Model of 38 Basins (Table VI)

B100 = Linear Model of 36 Basins (Table VII)

AB100L = Logarithmic Model of 36 Basins (Table VII)

NO = Number of Drainage Basins Corresponding to Appendix B

VIII, IX, X, XI, XII, and XIII, respectively, and the graph of predicted equations and flood peaks of selected recurrence intervals from Log Pearson Type III is shown in Figures 8 through 13.

Analysis of Result of Model

After analysis of 38 drainage basins by using stepwise regression techniques relating peak flow to six drainage basin characteristics and climatic conditions, the following results were noted. The drainage area was found to be the most significant variable, in terms of both R^2 (coefficient of determination) and the observed significance level of the coefficient. The peak flows of return periods of 2, 5, 10, 25, 50, and 100 years relating to drainage area were analyzed by using both linear and log models. The R^2 and standard error seemed to indicate a good prediction, but the residuals (peak flow from selected recurrence interval minus predicted flow from the model) indicate an inadequate prediction. The weighted least squares technique was found to improve the accuracy of the flow predictions and reduce the residuals.

The final results are shown in Tables VI and VII. For each peak flow from a given recurrence interval, the best models are shown. Table VI indicates the best models when all 38 basins are considered. Table VII indicates the best models when 36 basins are considered, with the two very large basins deleted.

When considering all 38 basins, log models give better predictions than do linear models, but the linear models seem to give better predictions when the drainage area is greater than 100,000 km^2 (see Tables VIII to XIII). Basins No. 12 and No. 19 (Appendix B) on the Mune River give greater residuals than do the other basins, so these two

TABLE XIV

TABLE OF COMPARED PREDICTED VALUES OF Q_2 AND FROM LOG PEARSON TYPE III

OBS	NO	Q2	PQ2	RESID2	DA
1	1	1013	907.201	105.799	43100
2	2	39	135.583	-96.583	401
3	3	110	141.040	-31.040	703
4	4	383	202.247	180.753	4090
5	5	238	150.744	87.256	1240
6	6	438	212.367	225.633	4650
7	7	130	147.672	-17.672	1070
8	8	255	152.551	102.449	1340
9	9	148	141.022	6.978	702
10	10	307	188.694	118.306	3340
11	11	421	165.563	255.437	2060
12	14	132	170.984	-38.984	2360
13	15	27	129.438	-102.438	61
14	16	64	134.282	-70.282	329
15	17	201	153.816	47.184	1410
16	18	464	643.363	-179.363	28500
17	20	153	138.275	14.725	550
18	21	140	151.955	-11.955	1307
19	22	76	138.763	-62.763	577
20	23	298	165.581	132.419	2061
21	24	285	180.851	104.149	2906
22	25	226	183.019	42.981	3026
23	26	173	143.191	29.809	822
24	27	237	215.078	21.922	4800
25	28	599	667.163	-68.163	29817
26	29	212	228.486	-16.486	5542
27	30	38	151.684	-113.684	1292
28	32	653	666.910	-13.910	29803
29	33	404	366.351	37.649	13171
30	34	73	150.003	-77.003	1199
31	35	66	138.564	-72.564	566
32	36	61	144.148	-83.148	875
33	37	117	366.568	-249.568	13183
34	38	42	136.396	-94.396	446
35	39	41	132.583	-91.583	235
36	40	158	148.522	9.478	1117

Q2 = Peak Flows in Recurrence Intervals of Two Years From Log Pearson Type III (cubic meters/sec)

PQ2 = Predicted Peak Flow From Recurrence Interval of Two Years From Model B2

RESID2 = Q2 - PQ2 (cubic meters/sec)

DA = Drainage Area in Square Kilometers

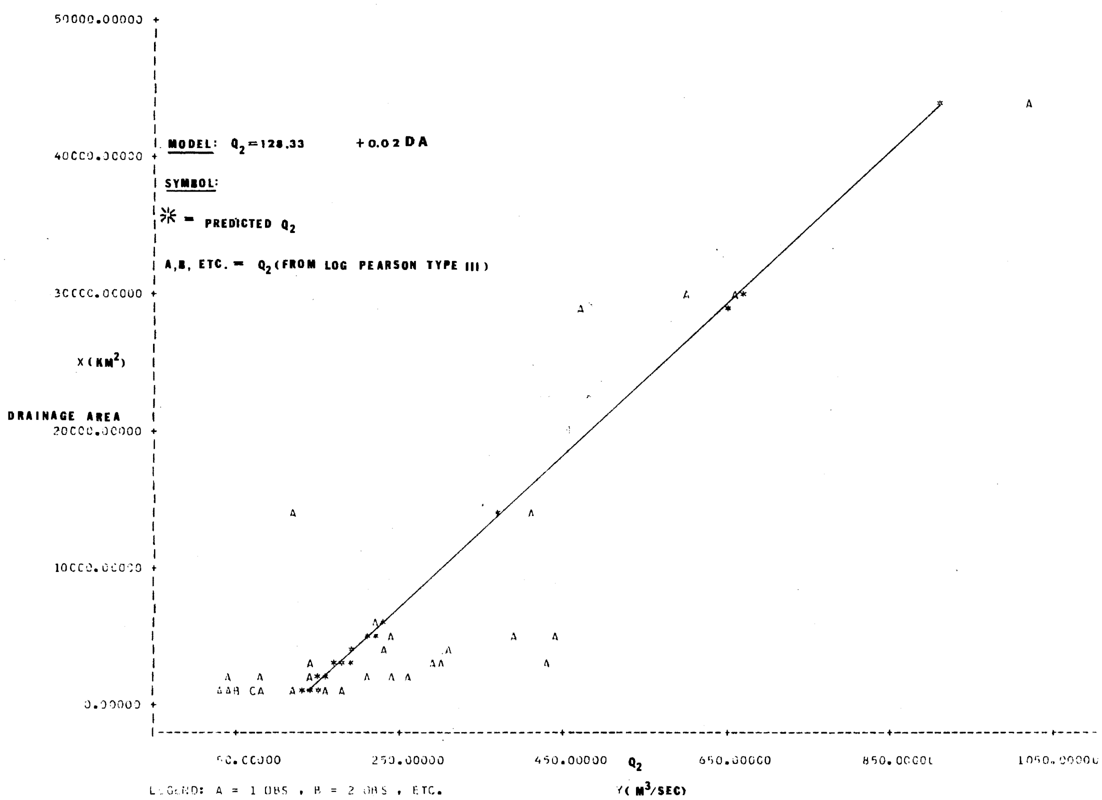


Figure 8. Relationship of Predicted Q_2 and Q_2 From Log Pearson Type III to Drainage Area

TABLE XV

TABLE OF COMPARED PREDICTED VALUES OF Q_5 AND FROM LOG PEARSON TYPE III

OBS	NO	Q5	PQ5	RESID5	DA
1	1	1293	1362.86	-69.858	43100
2	2	54	228.82	-174.816	401
3	3	156	236.84	-80.837	703
4	4	572	326.79	245.208	4090
5	5	471	251.10	219.901	1240
6	6	526	341.67	184.335	4650
7	7	178	246.58	-68.584	1070
8	8	383	253.76	129.245	1340
9	9	177	236.81	-59.811	702
10	10	498	306.87	191.127	3340
11	11	541	272.88	268.122	2060
12	14	173	280.85	-107.845	2360
13	15	40	219.79	-179.786	61
14	16	114	226.90	-112.904	329
15	17	298	255.61	42.386	1410
16	18	710	975.10	-265.097	28500
17	20	229	232.77	-3.774	550
18	21	230	252.88	-22.879	1307
19	22	106	233.49	-127.491	577
20	23	384	272.90	111.096	2061
21	24	543	295.35	247.654	2906
22	25	482	298.53	183.466	3026
23	26	322	240.00	82.002	822
24	27	543	345.65	197.351	4800
25	28	936	1010.07	-74.075	29817
26	29	442	365.36	76.644	5542
27	30	84	252.48	-168.480	1292
28	32	1154	1009.70	144.297	29803
29	33	941	567.97	373.026	13171
30	34	79	250.01	-171.010	1199
31	35	131	233.20	-102.198	566
32	36	129	241.41	-112.405	875
33	37	183	568.29	-385.293	13183
34	38	116	230.01	-114.011	446
35	39	70	224.41	-154.407	235
36	40	313	247.83	65.168	1117

Q5 = Peak Flows in Recurrence Intervals of 5 Years From Log Pearson Type III (cubic meters/sec)

PQ5 = Predicted Peak Flows from Recurrence Intervals of 5 Years From Model B5

RESID5 = Q5 - PQ5 (cubic meters/sec)

DA = Drainage Area in Square Kilometers

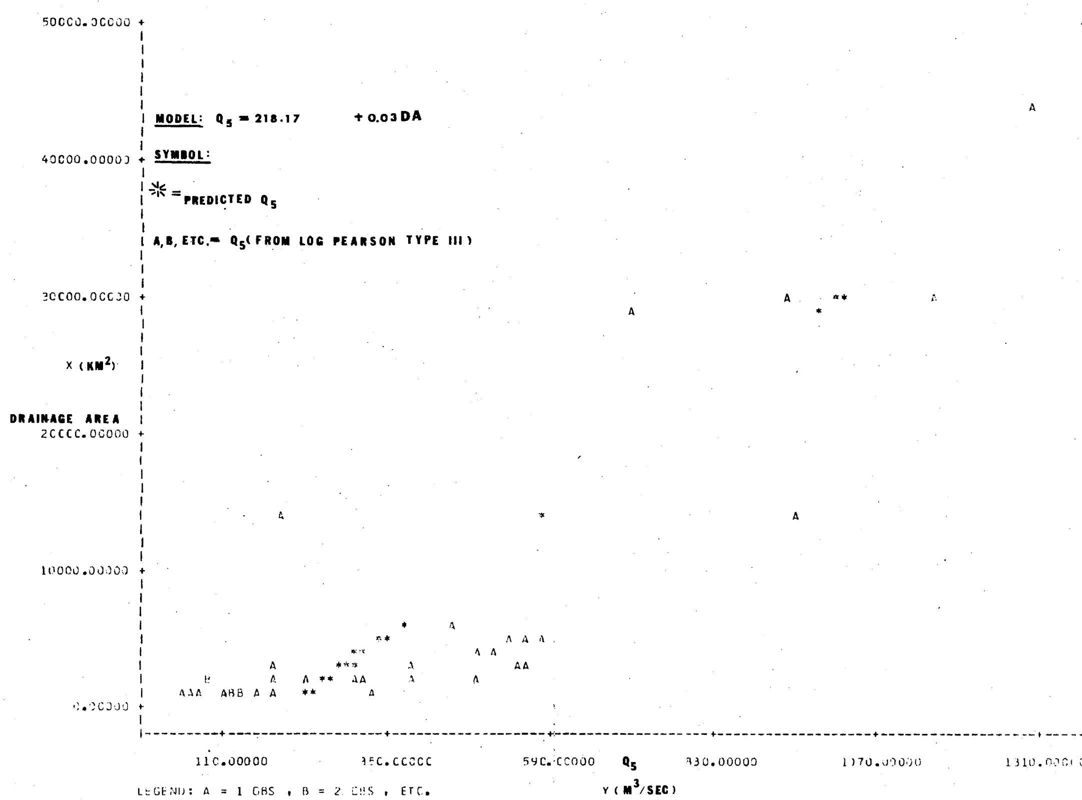


Figure 9. Relationship of Predicted Q_5 and Q_5 From Log Pearson Type III to Drainage Area

TABLE XVI

TABLE OF COMPARED PREDICTED VALUES OF Q_{10} AND FROM LOG PEARSON TYPE III

CBS	NO	Q10	PQ10	R10	DA
1	1	1473	1664.10	-191.095	43100
2	2	64	278.63	-214.626	401
3	3	196	288.42	-92.425	703
4	4	712	398.32	313.676	4090
5	5	743	305.85	437.151	1240
6	6	586	416.49	169.506	4650
7	7	195	300.33	-105.333	1070
8	8	473	309.09	163.906	1340
9	9	192	288.39	-96.392	702
10	10	677	373.99	303.012	3340
11	11	636	332.46	303.544	2060
12	14	196	342.19	-146.190	2360
13	15	48	267.59	-219.594	61
14	16	153	276.29	-123.289	329
15	17	342	311.37	30.635	1410
16	18	844	1190.36	-346.364	28500
17	20	278	283.46	-5.460	550
18	21	288	308.02	-20.023	1307
19	22	130	284.34	-154.336	577
20	23	432	332.49	99.512	2061
21	24	827	359.91	467.094	2906
22	25	647	363.80	283.200	3026
23	26	403	292.29	110.714	822
24	27	785	421.36	363.638	4800
25	28	1119	1233.10	-114.097	29817
26	29	641	445.44	195.562	5542
27	30	126	307.54	-181.536	1292
28	32	1481	1232.64	248.357	29803
29	33	1505	692.98	812.022	13171
30	34	81	304.52	-223.519	1199
31	35	196	283.98	-87.979	566
32	36	171	294.01	-123.006	875
33	37	241	693.37	-452.368	13183
34	38	189	280.09	-91.086	446
35	39	91	273.24	-182.239	235
36	40	452	301.86	150.142	1117

Q10 = Peak Flows in Recurrence Intervals of 10 Years From Log Pearson Type III (cubic meters/sec)

PQ10 = Predicted Peak Flows From Recurrence Intervals of 10 Years From Model B10

RESID10 = Q10-PQ10 (cubic meters/sec)

DA = Drainage Area in Square Kilometers

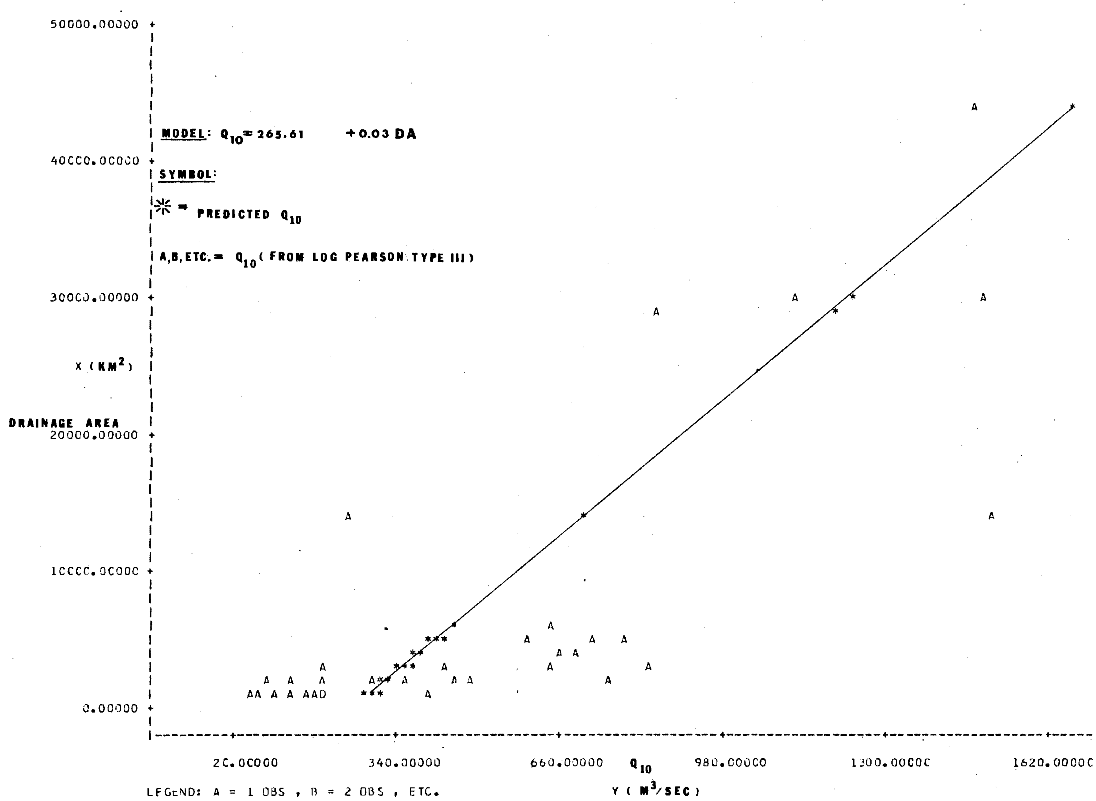


Figure 10. Relationship of Predicted Q_{10} and Q_{10} From Log Pearson Type III to Drainage Area

TABLE XVII

TABLE OF COMPARED PREDICTED VALUES OF Q_{25}
AND FROM LOG PEARSON TYPE III

OBS	NO	Q25	PQ25	R25	DA
1	1	1696	2014.95	-318.95	43100
2	2	78	340.99	-262.99	401
3	3	259	352.83	-93.83	703
4	4	908	485.61	422.39	4090
5	5	1303	373.88	929.12	1240
6	6	664	507.57	156.43	4650
7	7	206	367.22	-161.22	1070
8	8	593	377.80	215.20	1340
9	9	207	352.79	-145.79	702
10	10	978	456.21	521.79	3340
11	11	773	406.03	366.97	2060
12	14	222	417.79	-195.79	2360
13	15	57	327.66	-270.66	61
14	16	208	338.17	-130.17	329
15	17	381	380.55	0.45	1410
16	18	982	1442.58	-460.58	28500
17	20	336	346.83	-10.83	550
18	21	359	376.51	-17.51	1307
19	22	164	347.89	-183.89	577
20	23	486	406.07	79.93	2061
21	24	1391	439.20	951.80	2906
22	25	828	443.90	384.10	3026
23	26	480	357.50	122.50	822
24	27	1108	513.45	594.55	4800
25	28	1306	1494.21	-188.21	29817
26	29	942	542.54	399.46	5542
27	30	196	375.92	-179.92	1292
28	32	1867	1493.66	373.34	29803
29	33	2537	841.62	1695.38	13171
30	34	84	372.28	-288.28	1199
31	35	311	347.46	-36.46	566
32	36	223	359.57	-136.57	875
33	37	336	842.09	-506.09	13183
34	38	305	342.76	-37.76	446
35	39	122	334.48	-212.48	235
36	40	671	369.06	301.94	1117

Q25 = Peak Flows in Recurrence Intervals of 25 Years From Log Pearson Type III (cubic meters/sec)

PQ25 = Predicted Peak Flows From Recurrence Intervals of 25 Years From Model B_{25}

RESID25 = Q25 - PQ25 (cubic meters/sec)

DA = Drainage Area in Square Kilometers

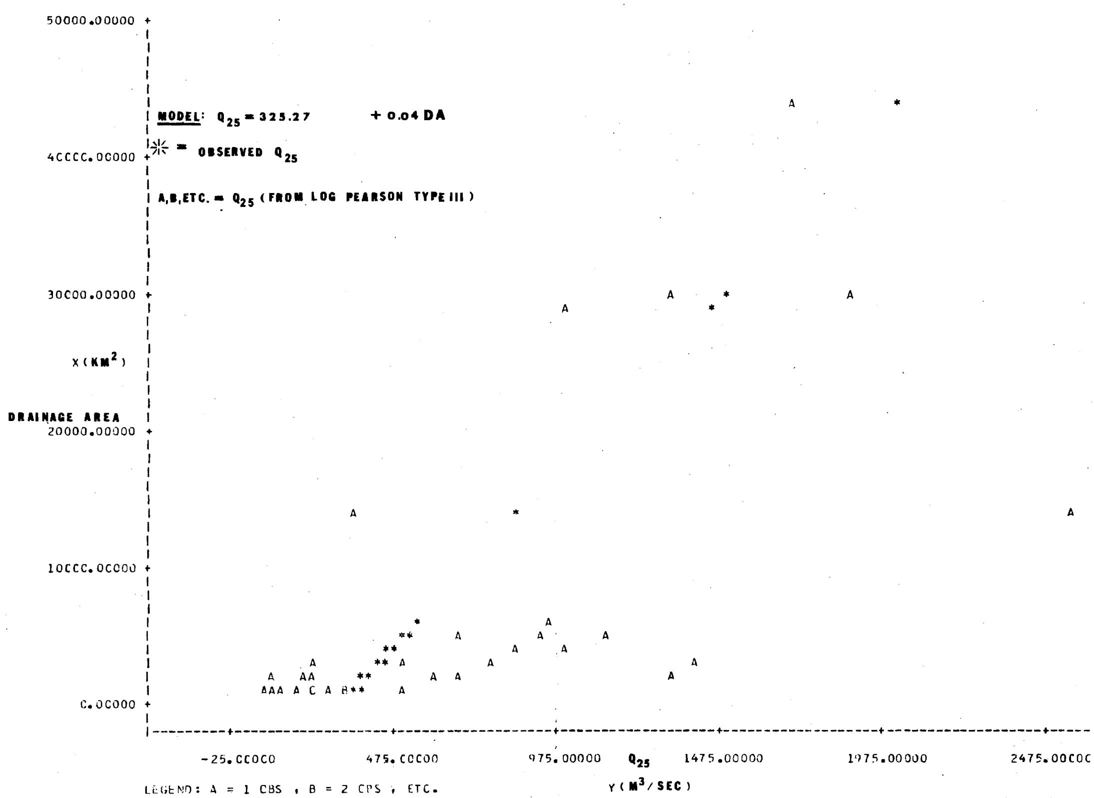


Figure 11. Relationship of Predicted Q_{25} and Q_{25} From Log Pearson Type III to Drainage Area

TABLE XVIII

TABLE OF COMPARED PREDICTED VALUES OF Q_{50} AND FROM LOG PEARSON TYPE III

OBS	NO	Q50	PQ50	R50	DA
1	1	1863	2250.54	-387.54	43100
2	2	88	388.57	-300.57	401
3	3	317	401.74	-84.74	703
4	4	1067	549.43	517.57	4090
5	5	1959	425.16	1533.84	1240
6	6	724	573.85	150.15	4650
7	7	210	417.74	-207.74	1070
8	8	687	429.52	257.48	1340
9	9	216	401.69	-185.69	702
10	10	1270	516.73	753.27	3340
11	11	890	460.91	429.09	2060
12	14	239	474.00	-235.00	2360
13	15	63	373.74	-310.74	61
14	16	254	385.43	-131.43	329
15	17	400	432.57	-32.57	1410
16	18	1064	1613.88	-549.88	28500
17	20	378	395.07	-17.07	550
18	21	409	428.08	-19.08	1307
19	22	194	396.24	-202.24	577
20	23	520	460.96	59.04	2061
21	24	2023	497.80	1525.20	2906
22	25	941	503.04	437.96	3026
23	26	551	406.93	144.07	822
24	27	1352	580.40	771.60	4800
25	28	1418	1671.31	-253.31	29817
26	29	1201	612.75	588.25	5542
27	30	259	427.42	-168.42	1292
28	32	2130	1670.70	459.30	29803
29	33	3597	945.43	2651.57	13171
30	34	86	423.37	-337.37	1199
31	35	427	395.76	31.24	566
32	36	260	409.24	-149.24	875
33	37	423	945.95	-522.95	13183
34	38	408	390.53	17.47	446
35	39	148	381.33	-233.33	235
36	40	869	419.79	449.21	1117

Q50 = Peak Flows in Recurrence Intervals of 50 Years From Log Pearson Type III (cubic meters/sec)

PQ50 = Predicted Peak Flows From Recurrence Intervals of 50 Years From Model B50

R50 = Q50 - PQ50 (cubic meters/sec)

DA = Drainage Area in Square Kilometers

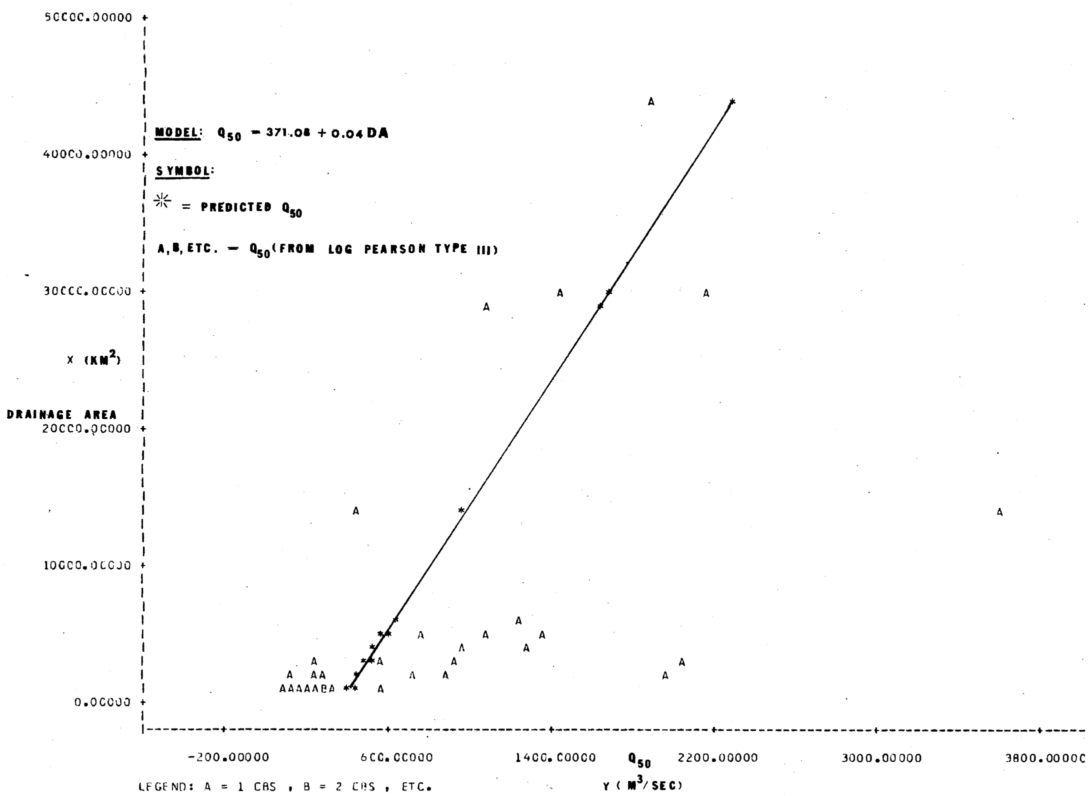


Figure 12. Relationship of Predicted Q_{50} and Q_{50} From Log Pearson Type III to Drainage Area

TABLE XIX

TABLE OF COMPARED PREDICTED VALUE Q_{100} AND FROM LOG PEARSON TYPE III

CBS	NO	Q100	PQ100	R100	DA
1	1	2023	2462.33	-439.33	43100
2	2	98	437.16	-339.16	401
3	3	386	451.48	-65.48	703
4	4	1237	612.12	624.88	4090
5	5	2914	476.95	2437.05	1240
6	6	786	638.68	147.32	4650
7	7	211	468.89	-257.89	1070
8	8	783	481.69	301.31	1340
9	9	223	451.43	-228.43	702
10	10	1633	576.55	1056.45	3340
11	11	1018	515.84	502.16	2060
12	14	255	530.07	-275.07	2360
13	15	70	421.03	-351.03	61
14	16	302	433.74	-131.74	329
15	17	414	485.01	-71.01	1410
16	18	1133	1769.86	-636.86	28500
17	20	417	444.22	-27.22	550
18	21	456	480.13	-24.13	1307
19	22	227	445.51	-218.51	577
20	23	552	515.89	36.11	2061
21	24	2911	555.97	2355.03	2906
22	25	1035	561.66	473.34	3026
23	26	552	457.13	94.87	822
24	27	1593	645.80	947.20	4800
25	28	1510	1832.33	-322.33	29817
26	29	1490	680.99	809.01	5542
27	30	333	479.42	-146.42	1292
28	32	2371	1831.66	539.34	29803
29	33	4966	1042.83	3923.17	13171
30	34	87	475.01	-388.01	1199
31	35	576	444.98	131.02	566
32	36	295	459.64	-164.64	875
33	37	528	1043.39	-515.39	13183
34	38	523	439.29	83.71	446
35	39	176	429.28	-253.28	235
36	40	1099	471.12	627.88	1117

Q100 = Peak Flows in Recurrence Intervals of 100 Years From Log Pearson Type III (cubic meters/sec)

PQ100 = Predicted Peak Flows From Recurrence Intervals of 100 Years From Model B100

R100 = Q100 - PQ100 (cubic meters/sec)

DA = Drainage Area in Square Kilometers

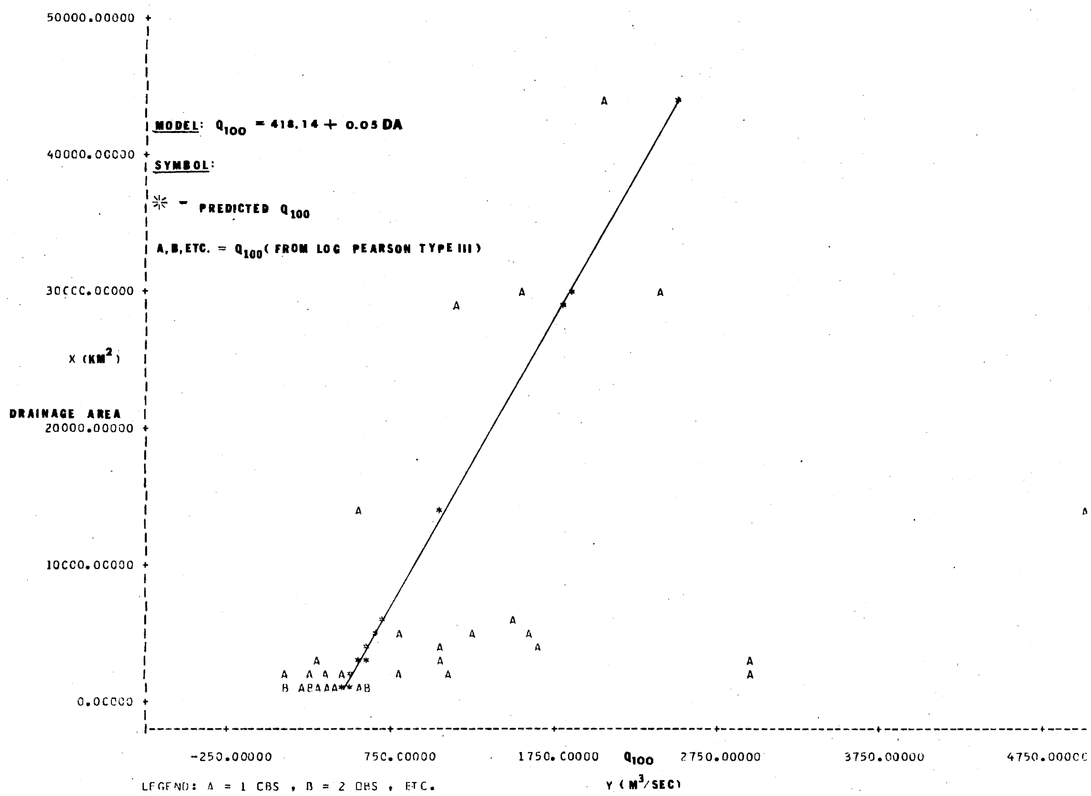


Figure 13. Relationship of Predicted Q_{100} and Q_{100} From Log Pearson Type III to Drainage Area

basins are omitted, leaving 36 basins. The other reason for omitting these two basins was to check the prediction when the drainage area sizes are smaller than 43,1000 square kilometers. In the analysis of the 36 small basins, the linear model gives a better prediction. The logarithmic models indicate good R^2 and standard error, but do not give a good prediction (Tables VI and VII). Based on the value of the residual, linear models were found to give a good prediction (see Tables VIII and XIV).

The author would like to recommend the use of the following models: If the drainage area sizes are smaller than 50,000 square kilometers, use models B2, B5, B10, B25, B50, and B100, to estimate Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, and Q_{100}. Tables XIV to XIX and Figures 8 to 13 show the residuals between the predicted and Log Pearson Type III values. The utilization of the models in a simple and practical way is presented in the Engineering Application section.

Limitations

The following limitations should be observed when using the regression models:

1) They should not be used where dams, flood detention structures, and other man-made works have a significant effect on peak discharges. Under such conditions, stream systems studies involving reservoir and open channel routing may be required to evaluate flood frequency, which is beyond the scope of this thesis.

2) They should not be used in urban areas unless the effects of urbanization are not significant.

It should be noted that the predicted values given in Table V in the linear models are the best unbiased estimates of stream flow. The maximum Q_T to be expected can be established with 100 (1-α) percent confidence by computing a one-sided confidence interval. This can be computed from the formula

$$Q_T^* = (a\text{-}bA_o) + t_{35,\alpha} S_T (1A_o) C_T \begin{pmatrix} 1 \\ A_o \end{pmatrix} \qquad (5.4)$$

where A_o is the drainage area of the basin for which the estimate is desired, a, b, and S^2_T are given in Table V for the appropriate model, $t_{35,\alpha}$ is the upper α point of the student t distribution with 35 degrees of freedom, and C_T is given in Table XX for the models named B_2, B_5, B_{10}, B_{25}, B_{50}, and B_{100}.

Engineering Application

As an engineering consideration, the model should be simple to use in the engineering field. The models named B2, B5, B10, B25, B50, and B100 are presented in the form of:

$$Q_2 = 128 + 0.02\ DA \qquad (B2) \qquad (5.4)$$

$$Q_{10} = 265 + 0.03\ DA \qquad (B10) \qquad (5.6)$$

$$Q_{25} = 289 + 0.04\ DA \qquad (B25) \qquad (5.7)$$

$$Q_{50} = 330 + 0.05\ DA \qquad (B50) \qquad (5.8)$$

$$Q_{100} = 418 + 0.05\ DA \qquad (B100) \qquad (5.9)$$

The relationships of Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, and Q_{100} to drainage are shown in Figure 14. The graph has the same practical predictive value as the equations (5.4) through (5.9).

TABLE XX

C_T MATRICES

T = 2	2.48338031172D-03	-9.74887527567D-08
	-9.74887527567D-08	1.35445682559D-11
T = 5	7.89704011688D-03	-2.85524000103D-07
	-2.85524000103D-07	3.16807494210D-11
T = 10	1.28073475287D-02	-4.61533524065D-07
	-4.61533524065D-07	4.89655719597D-11
T = 25	1.99507659630D-02	-7.18904092411D-07
	-7.18904092411D-07	7.40576482919D-11
T = 50	2.56621596241D-02	-9.24882661381D-07
	-9.24882661381D-07	9.40037663212D-11
T = 100	3.15324943495D-02	-1.13630369537D-06
	-1.13630369537D-06	1.14197590914D-10

D = power of ten.

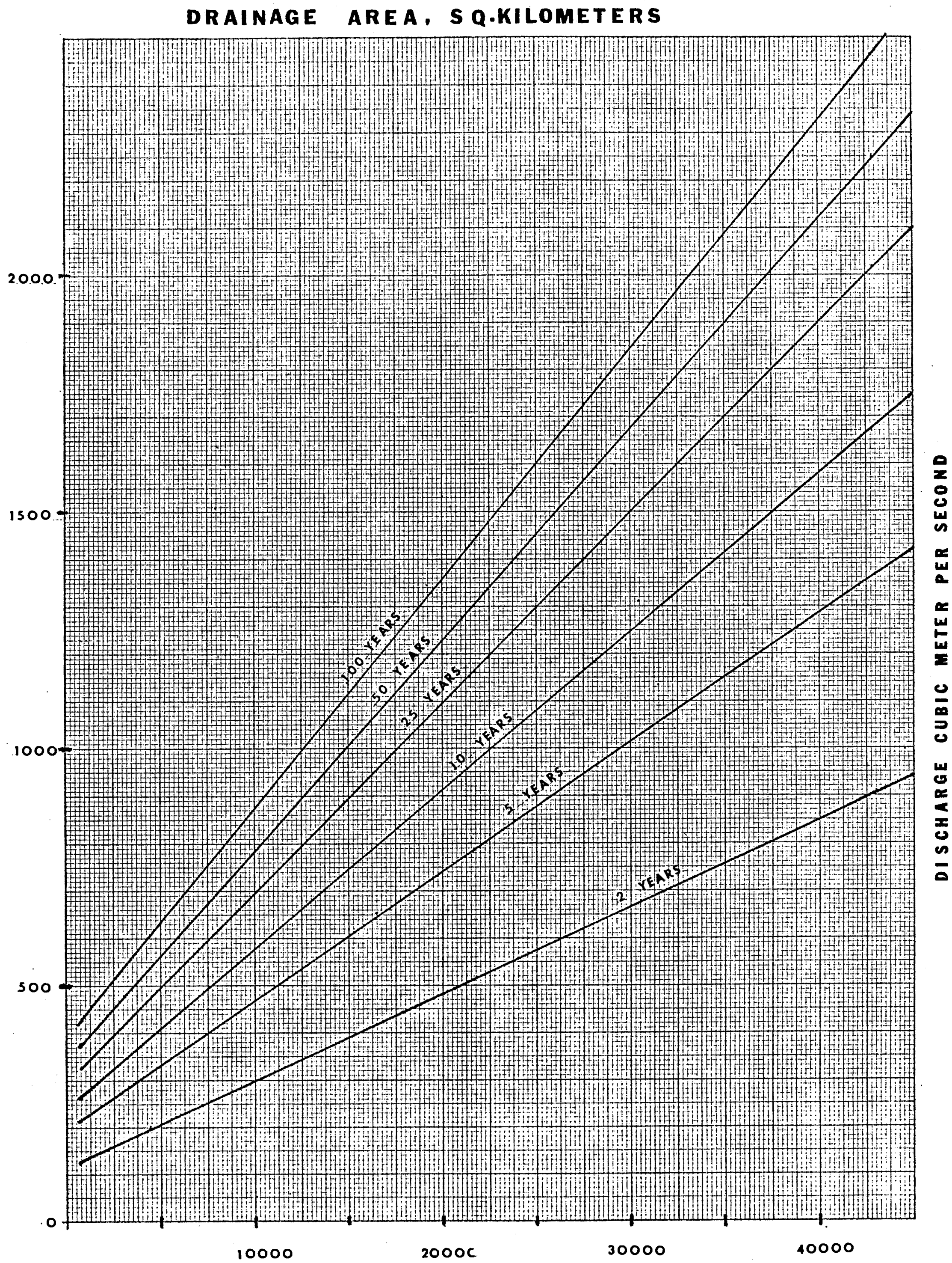


Figure 14. Peak Flow at Recurrence Intervals of 2, 5, 10, 25, 50, and 100 Years versus Drainage Areas

Maximum Flood Record of Northeastern Thailand

For each of the 38 drainage basins, the maximum flow or record was selected from the lists of annual peak flows in Appendix B. These maximum recorded flows are listed in Table XXI, and Figure 15 shows the relationship between maximum recorded flow and drainage area.

The graph can be used to approximate the maximum flow to be expected from a drainage basin of a given size.

TABLE XXI

MAXIMUM DISCHARGE IN NORTHEASTERN THAILAND

Drainage Area Km^2	Drainage Area $Mile^2$	M^3/Sec	Ft^3/Sec	$M^3/Sec/Km^2$	$Ft^3/Sec/Mile^2$	Basin No.
43100	16641	1920	57796	.045	4.07	1
401	155	72	2543	.18	16.406	2
703	271	261	9216	.371	34.000	3
4090	1579	747	26377	.183	16.70	4
1240	479	913	32238	.736	67.302	5
4650	1796	644	22740	.138	12.66	6
1070	413	190	6709	.177	16.244	7
1340	931	514	18150	.383	19.5	8
702	271	191	6744	.272	25.0	9
3340	1289	1150	40606	.344	31.50	10
2060	796	691	24399	.335	30.65	11
10400	40154	5540	195618	.053	4.87	12
2360	912	212	7485	.09	8.20	14
61	24	44	1544	.721	64.75	15
329	127	197	6956	.598	54.77	16
1410	544	346	12217	.245	22.45	17
28500	11004	803	28354	.028	2.58	18
117000	45174	6640	234811	.057	5.19	19
550	212	252	8898	.458	41.97	20
1307	505	331	11688	.253	23.144	21
577	223	157	5544	.272	24.86	22
2061	796	500	17655	.242	22.18	23
2906	1122	1509	53283	.519	47.489	24
3026	1168	760	36836	.251	31.54	25
822	318	479	16914	.582	53.19	26
4800	1853	1136	40112	.236	21.64	27
29817	11512	1108	39123	.037	3.398	28
5542	2139	639	22563	.115	10.548	29
1292	499	115	4061	.089	8.138	30
29803	11506	1453	51306	.049	4.459	32
13171	5085	1840	64970	.139	12.776	33
1199	463	82	2896	.068	6.25	34
566	219	326	11511	.575	52.56	35
875	338	171	6038	.195	17.86	36
13183	5090	277	9781	.021	1.92	37
446	172	276	9746	.618	56.66	38
235	91	108	3814	.460	41.9	39
1117	432	527	18609	.472	43.076	40

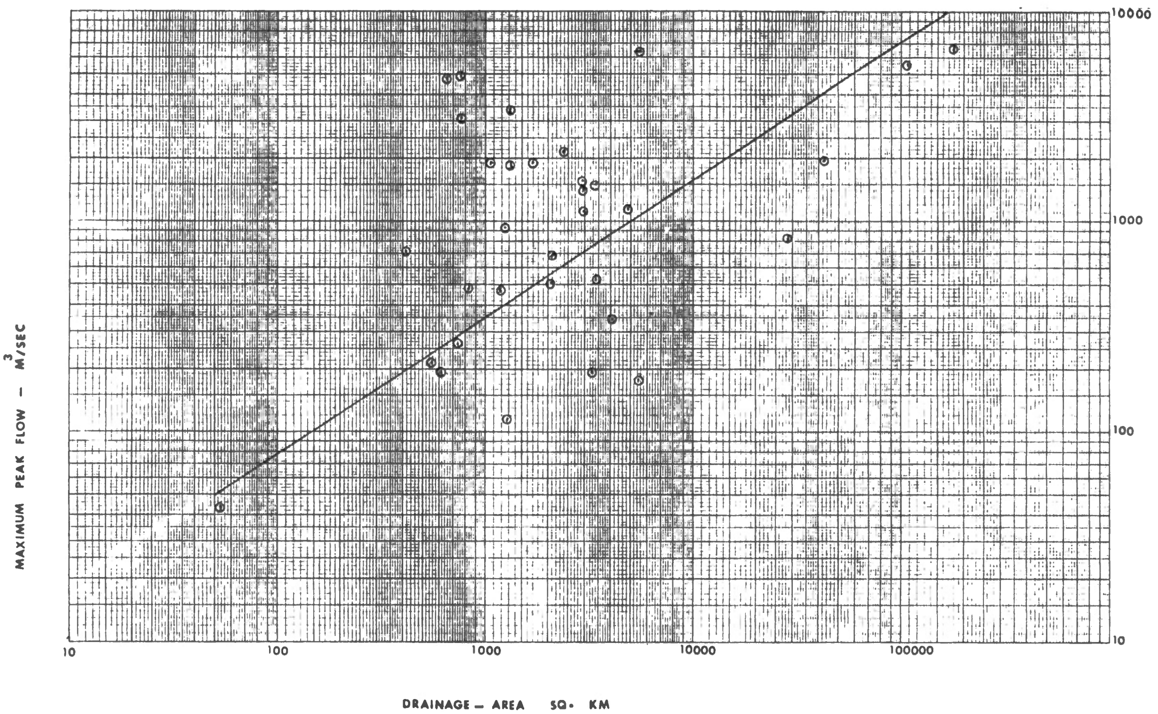


Figure 15. Relation of Maximum Flood to Drainage Area in Northeastern Thailand

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary

The regional flood flow frequency analysis had never been made in Thailand. Therefore, flood records at 38 gaging stations in northeastern Thailand have been used in analysis for this report. The flood frequency relation and associated statistics were derived for 38 stations that have five or more years of record by fitting the array of annual peaks to a Log-Pearson Type III distribution. Selected recurrence-interval floods from the 2-year through the 100-year level were tabulated for each record, depending on the number of years of record used to calculate the flood frequency curve.

The flood frequency data for the 38 basin drainage areas were related to basin characteristic and climatology through multiple linear regression techniques. Of the variables considered, the only significant variable was drainage area. By excluding the two large drainage basins of the Mune River and making a linear model of the remaining 36 basins, a better result was obtained (see Tables VIII and XIII). Equations were developed for the 2-, 5-, 10-, 25-, 50-, and 100-year floods. A weighted least squares procedure based on length of record is recommended to adjust the equation.

Conclusions

The objective of this research is to use a new way of flood frequency technique that has never been used in Thailand and should be useful to estimate the flood frequency of a stream at an ungaged site if the drainage area sizes are known.

After analysis, the linear models named B2, B5, B10, B25, B50, and B100, gave better results than did other models (see summary of results in Tables VIII to XIII; note the standard error and R^2 in Tables VI and VII). The selected model was based on the residual of the results (discharge of Log Pearson Type III at selected recurrence interval - predicted discharge from model).

The utilization of this model under upper confidence limit was shown in the section on limitation of model and Table XX for each recurrence interval--2, 5, 10, 25, 50, and 100 years. The result of these predictions is only fair, because of insufficient data. The graph of drainage area versus observed discharge for selected recurrence interval and predicted discharge is shown in Tables XIV to XIX. For the engineering practical application in the field, it has been summarized in engineering consideration. It summarizes equations (5.4), (5.5), (5.6), (5.7), (5.8), and (5.9) for recurrence intervals of 2, 5, 10, 25, 50, and 100 years, respectively. It also included the corresponding graph, which is shown in Figure 14 for use in the engineering field.

This research will be useful as a guide for future study. Further studies are planned when the author of this paper returns to his country (Thailand). The use of more independent variables as characteristic of drainage basins and more accurate topographic maps would be useful for future studies. Also, digital simulation computer models would be of use to extend the streamflow records.

CHAPTER VII

SUGGESTIONS FOR FUTURE STUDY

These suggestions for future study would be useful for future water resources research in northeastern Thailand and other parts of Thailand.

1) Do regional flood frequency analyses by use of a multiple regression technique for another part of Thailand, e.g., the south, east, north, and central areas.

2) Use a multiple regression technique to predict low flow frequency with relation to the characteristics and climatology of the drainage basins.

3) Use a multiple regression technique to relate the water quantity and quality.

4) Construct skew coefficient map to adjust the data to give better results of flood flow frequency, and use the multiple regression technique to fit the characteristics and climatology of drainage basins of the study areas.

5) Use a multiple regression technique to predict the water yield in northeastern Thailand.

6) Do sediment yield of watershed in northeastern Thailand by use of the multiple regression technique.

BIBLIOGRAPHY

1. Committee for Co-ordination of Investigations of the Lower Mekong Basin: Flood Frequency Study of the Mekong, MKG/7 (June 28, 1973).

2. Clarke-Hafstad, K., "Reliability of Station-Year Rainfall Frequency Determinations." Trans. ASCE, V. 107, pp. 632-683 (1942).

3. Longbein, W. B., "Topographic Characteristics of Drainage Basins." U. S. Geological Survey, Water Supply Paper 968C, pp. 125-157 (1947).

4. Dalrymple, T., "Flood Frequency Analyses." U. S. Geological Survey, Water Supply Paper 1543A (1960).

5. Benson, M. A., "Evolution of Methods for Evaluating the Occurrence of Floods." U. S. Geological Survey Water Supply Paper 1580A (1962).

6. Benson, M. A., Matalas, N. C., Synthetic Hydrology Based on Regional Statistical Parameters. Water Resources Research, Vol. 3, No. 4, pp. 931-936 (1967).

7. U. S. Geological Survey Water Supply Paper, 1671-1689 (1964).

8. Pravatmuong, P., The Hydrology of the Lower Mekong River With Particular Reference to Pa Mong Project, Asian Institute of Technology, Thesis No. 51 (1964).

9. U. S. B. R., Pa Mong, "Key to the Development of the Lower Mekong," Data Summary (1973).

10. Rjoanasoonthorn, S., and Moorman, F. R., "The Soils of the Kingdom of Thailand Explanatory Text of the General Soil Map." Report SSR-72A, Soil Survey Division, Bangkok, Thailand.

11. Pinkayan, S, and Sahagun, V. A., "Hydrologic Study of the Thung Ma Hiu Project, Asian Institute of Technology Research, Report No. 42, September (1973).

12. Molagool, A., An Investigation of the Water Balance in Northeastern Thailand. Thesis No. 32, Asian Institute of Technology (1962).

13. Paddleton, R. L. Report to Accompany the Provisional Map of the Soils and Surface Rocks of the Kingdom of Siam (unpublished). Mutual Security Agency, U. S. Special Technical and Economic Mission to Thailand (1953).

14. U. S. B. R., Pa Mong Phase II, Appendix III, "Hydrology and Climatology." Prepared for the Committee for Coordination of Investigations of the Lower Mekong Basin and the Agency for the International Development (1972).

15. U. S. B. R., Pa Mong Phase I, Appendix III. "Hydrology and Climatology." Prepared for the Committee for Coordination of Investigations of the Lower Mekong Basin and the Agency for the International Development (1970).

16. Information From Royal Thai Irrigation Department.

17. National Energy Authority of Thailand, Hydrologic Data, Vol. I and Vol. II (1962-1971).

18. Riggs, H. C., Regional Analysis of Stream Flow Characteristics. U. S. Geological Survey Techniques of Water Resources Inv., Book 4, Chap. B3, 15 p. (1973).

19. Beard, L. R., Statistical Methods in Hydrology. U. S. Army Engineer District, Corps of Engineers, Sacramento, Calif., Section 7 (1962).

20. Benson, M. A., "Evolution of Methods for Evaluating the Occurrence of Floods." U. S. Geological Survey Water Supply Paper 1580A, 30 p. (1962).

21. Riggs, H. C., "A Method of Forecasting Low Flow of Streams." Am. Geophys. Union Trans., V. 34, No. 3, pp. 427-434 (1953).

22. Water Resources Council, Hydrology Committee. "A Uniform Technique for Determining Flood Flow Frequencies." Bulletin No. 15, Washington, D. C. (1967).

23. U. S. Water Resources Council. "A Uniform Technique for Determining Flood Flow Frequencies." Draft, Washington, D. C., December 3 (1974).

24. U. S. Geological Survey, "Log Pearson Type III Flood Frequency Analysis Computer Program E657-451" (Revision by D. B. Sapek) (August, 1974).

25. Yeojavich, V., Handbook of Hydrology, by V. T. Chow, Section 8-11, McGraw-Hill Book Company, New York (1964).

26. Draper, N. R., and Smith, H., Applied Regression Analysis. John Wiley & Sons, Inc., New York (1967).

27. Neter, V., and Wasserman, W., Applied Linear Statistical Model. Richard D. Irwin, Inc., New York (1974).

28. Royal Thai Irrigation Department, Thailand Hydrologic Year Book, Vol. 5-8, Bangkok, Thailand (1959-1965).

29. National Energy Authority, Ministry of National Development, Hydrologic Data, Vol. I and Vol. II, Bangkok, Thailand (1962-1972).

30. Supplemental Data From Royal Thai Irrigation Department, by Mr. Lek Chindasaguan (1973-1974).

31. Supplemental Data From National Energy Authority, Ministry of National Development, by Mrs. Suntraphorn Suthaswin (1972-1973).

32. Harza Engineering Company, Hydrologic Data Mekong River Basin (1960-1961).

33. Sauer, V. B., Flood Characteristics of Oklahoma Streams. U. S. Geological Survey Water Resources Investigation, 52-73 (1974).

34. Royal Thai Army, Topographic Map Scales 1:250,000 (1969).

35. Kendall, M. G., The Advanced Theory of Statistics, Vol. I, 5th Ed., Hafner Publishing Co., New York (1952).

36. Hardison, C. H., "Accuracy of Stream Flow Characteristics." U. S. Geological Survey Professional Paper 650-D, pp. 210-214 (1969).

37. LaMoreaux, P. E., et al., "Reconnaissance of the Geology and Groundwater of the Khorat Plateau, Thailand." U. S. Geological Survey Water Supply Paper 1429 (1958).

38. Anderson, J. A., "Runoff Evaluation and Streamflow Simulation by Computer." U. S. Army Engineering Division, North Pacific, Portland, Oregon (May, 1971).

39. Rockwood, D. M., and Anderson, J. A., "Probable Maximum Floods for Mekong River Project." Presented at the ASCE National Meeting on Water Resources Engineering, New Orleans, La., (February 3-7, 1969).

40. Martin, R. C., "Low Flow Simulation of the Illinois River Using a Conceptual Hydrologic Model." Unpublished Masters Thesis, Oklahoma State University (1975).

41. "National Weather Service River Forecast System Forecast Pro-Procedures." NOAA Technical Memorandum NWS HYDRO 14. Department of Commerce (1972).

42. Linsley, R., "A Critical Review of Currently Available Hydrologic Models for Analysis of Urban Stormwater Runoff." Hydrocomp International (1972).

43. Burnash, R. J. C., Ferral, R. L., and McGuire, R. A., "A Generalized Streamflow Simulation System." U. S. Department of Commerce and State of California Department of Water Resources (1973).

44. Crawford, N. H., and Linsley, R. K., "Digital Simulation in Hydrology. Stanford Watershed Model IV." Technical Report No. 39, Stanford University (1966).

45. Thomas, B. J., Corps of Engineers, North Pacific Division, Portland, Oregon. Personal Communication (1975).

46. Service, Jolayne. A User's Guide to the Statistical Analysis System. North Carolina State University, Raleigh (August, 1972).

47. Linsley, R., Kohler, M. A., and Paulhus, J. L. H., Hydrology for Engineers. McGraw-Hill Book Company, New York (1975).

48. Royal Thai Irrigation Department Loose-leaf Report of Precipitation and Climatic Data 1951-1971, Bangkok, Thailand.

49. Thornethwaite, C. W.,"An Approach Toward a Rational Classification of Climate, 1948." Geological Review, Vol. 38, pp. 55-94

APPENDIX A

CLIMATOLOGIC DETAILS OF NORTHEASTERN THAILAND

TABLE XXII

CLIMATOLOGICAL DATA FOR THE PERIOD 1951-1970

Station LOEI	Elevation of station above MSL 252.52 meters
Index Station 48 353	Height of barometer above MSL 253.99
Latitude 17° 32' N.	Height of thermometer above ground 1.21
Longitude 101° 30' E.	Height of wind vane above ground 11.30
	Height of rainguage 0.65

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Evaporation (mm)													
Mean - Piche	77.6	95.3	121.0	104.2	68.2	54.1	56.7	48.1	35.4	44.5	50.5	62.6	818.2
- Pan	119.8	129.8	161.2	166.0	144.8	128.2	134.3	119.7	101.8	119.6	110.5	114.9	1550.6
Cloudiness (0-8)													
Mean	2.4	2.4	2.6	3.7	5.5	6.3	6.4	6.5	6.1	4.3	3.3	2.9	4.4
Visibility (Km)													
0700 LST	1.8	1.8	1.5	2.5	5.0	5.9	6.1	5.5	3.8	2.5	1.8	1.8	3.3
Mean	6.0	4.2	3.1	4.9	8.6	9.4	9.5	9.1	8.4	8.4	8.2	7.6	7.3
Wind (knots)													
Prevailing	E	E	E	E	W	W	W	W	N	N	N	N	-
Mean speed	3.5	3.9	3.8	3.9	3.6	3.3	3.9	3.6	3.2	2.9	2.8	3.0	-
Max. speed	30 NW	27 SES	40NSW	47 W	45 N	40 SW	33 NW	33 W	35 NW	33 N	21 NE	21 N	-
Rainfall (mm)													
Mean	7.3	14.4	52.5	93.0	189.4	156.2	143.2	196.3	248.0	104.1	14.1	2.9	1221.4
Mean rainy days	1.8	3.2	5.7	9.3	19.5	18.5	17.9	21.6	20.3	11.4	2.8	0.9	132.9
Greatest in 24 hr	17.0	28.0	61.8	66.4	87.4	102.8	59.9	118.5	148.6	102.3	33.7	23.3	148.6
Day/year	19/69	9/56	26/55	4/55	4/68	1/57	21/68	29/58	23/67	9/64	1/69	22/66	23/67
No. days with													
Haze	27.9	26.8	30.5	27.8	15.2	8.2	5.8	5.6	7.3	13.9	17.4	22.6	209.0
Fog	12.5	5.5	3.4	1.1	2.1	3.4	4.7	5.7	9.6	16.8	19.2	17.9	101.9
Hail	0.0	0.1	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
Thunderstorm	0.5	1.6	7.9	18.5	23.6	16.1	13.4	15.3	11.8	7.0	0.7	0.0	116.4
Squall	0.0	0.0	0.2	0.5	0.2	0.1	0.1	0.0	0.1	0.0	0.0	0.0	1.2

Remark: Data for 1954-1970

TABLE XXIII

CLIMATOLOGICAL DATA FOR THE PERIOD 1951-1970

Station NAKHON PHANOM	Elevation of station above MSL	140.00 meters
Index Station 48 357	Height of barometer above MSL	141.00
Latitude 17° 30' N.	Height of thermometer above ground	1.20
Longitude 104° 20' E.	Height of wind vane above ground	13.80
	Height of rainguage	0.80

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Evaporation (mm)													
Mean - Piche	93.4	95.0	105.3	100.1	67.0	45.6	41.0	37.1	42.0	70.6	86.5	88.8	872.4
- Pan					No observation								
Cloudiness (0-8)													
Mean	2.4	3.2	3.5	4.4	5.7	6.8	6.8	6.9	6.4	4.4	3.4	2.7	4.7
Visibility (Km)													
0700 LST	4.9	5.6	5.8	7.0	10.2	9.4	9.6	8.5	9.2	9.6	7.5	5.2	7.7
Mean	10.8	9.0	7.5	8.7	11.6	11.0	11.1	10.7	11.2	12.2	12.6	11.8	10.7
Wind (knots)													
Prevailing	E	E	E	E	E	E	E	E	E	E	E	E	-
Mean speed	4.6	4.5	3.9	3.3	3.1	2.6	2.9	3.0	2.6	3.3	4.0	4.3	-
Max. speed	27NE	50W	39N	40NW	55WSW	22SW	27S	34W	48S	26E	30E	30NE	-
Rainfall (mm)													
Mean	7.1	18.5	51.9	85.3	242.5	529.1	377.3	588.3	355.1	58.4	4.4	0.0	2317.9
Mean rainy days	0.9	2.7	5.6	8.2	18.8	22.7	23.4	24.8	20.9	7.4	1.4	0.0	136.8
Greatest in 24 hr	43.5	60.5	58.9	110.4	124.0	459.2	155.8	264.0	146.0	105.4	27.2	0.0	459.2
Day/year	25/54	28/54	6/61	30/67	26/69	17/62	3/69	16/60	15/54	1/64	1/63	0/0	17/62
No. days with													
Haze	22.6	24.3	27.8	22.9	5.2	0.3	0.3	0.1	2.9	11.0	15.6	19.8	152.8
Fog	6.9	5.4	3.4	2.9	1.8	0.7	0.3	0.6	1.7	4.6	5.8	10.1	44.2
Hail	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Thunderstorm	0.2	1.1	5.4	10.1	18.4	18.6	16.5	14.6	10.6	4.6	0.2	0.1	100.4
Squall	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1

Remark:
1. Pressure 1953-1970
2. Temperature 1952-1970
3. Evaporation 1957-1970

TABLE XXIV

CLIMATOLOGICAL DATA FOR THE PERIOD 1951-1970

Station SAKHON NAKHON	Elevation of station above MSL 172.00 meters
Index Station 48 356	Height of barometer above MSL 173.00
Latitude 17° 10' N.	Height of thermometer above ground 1.20
Longitude 104° 09' E.	Height of wind vane above ground 14.50
	Height of rainguage 0.63

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Evaporation (mm)													
Mean - Piche	94.9	96.6	116.8	102.8	67.5	52.0	55.4	47.5	44.6	71.5	84.9	84.7	919.2
- Pan	199.1	200.0	254.7	222.9	176.5	148.5	164.9	149.0	141.8	200.7	204.8	198.1	2261.0
Cloudiness (0-8)													
Mean	2.4	2.8	3.1	4.1	5.8	6.6	6.5	6.8	6.1	4.1	3.3	2.6	4.5
Visibility (Km)													
0700 LST	5.3	5.3	5.8	7.5	9.5	9.2	9.6	9.2	8.6	9.0	8.1	5.7	7.7
Mean	8.3	7.6	7.3	8.6	10.3	10.4	10.7	10.4	10.1	10.7	10.4	9.4	9.5
Wind (knots)													
Prevailing	E	E	E	E	S	S	SW	SW	E	E	E	E	-
Mean speed	4.7	5.0	4.7	4.2	3.4	3.7	4.1	3.9	3.2	3.8	4.2	4.2	-
Max. speed	33NE	32W	44N NW	50W	45N	35W	33N ESE	40SW	33NE SE	28N	24NE E	30NE	-
Rainfall (mm)													
Mean	7.0	15.2	48.0	77.4	222.0	266.6	198.8	287.9	274.9	60.4	6.6	0.9	1465.7
Mean rainy days	1.1	2.8	5.6	7.7	18.2	19.1	18.9	22.9	19.3	7.2	1.2	0.3	124.3
Greatest in 24 hr	26.6	52.6	73.6	69.7	106.5	131.6	184.2	115.0	214.3	93.9	52.2	14.4	214.3
Day/year	19/69	3/53	1/60	9/54	29/54	17/53	11/69	12.56	15.54	5/62	9/63	16/66	15/54
No. days with													
Haze	25.4	24.8	25.9	20.3	3.2	0.2	0.3	0.0	2.6	8.3	15.7	23.6	150.3
Fog	7.2	7.3	8.3	6.3	0.7	0.2	0.3	0.0	1.0	1.3	2.7	6.8	42.1
Hail	0.0	0.0	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Thunderstorm	0.3	0.9	4.4	10.2	14.1	10.5	8.6	8.8	6.7	2.3	0.4	0.0	67.2
Squall	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.2

Remark:
1. Pressure 1953-1970
2. Temperature 1952-1970
3. Evaporation 1957-1970

TABLE XXV

CLIMATOLOGICAL DATA FOR THE PERIOD 1951-1970

Station MUKDAHAN	Elevation of station above MSL 138.00 meters
Index Station 48 383	Height of barometer above MSL 139.00
Latitude 16° 33' N.	Height of thermometer above ground 1.50
Longitude 104° 44' E.	Height of wind vane above ground 10.50
	Height of rainguage 0.80

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Evaporation (mm)													
Mean - Piche	113.0	118.3	140.4	126.3	83.9	58.5	55.2	47.0	44.4	75.0	89.7	104.9	1056.6
- Pan					No observation								
Cloudiness (0-8)													
Mean	2.7	3.2	3.4	4.4	5.9	6.6	6.6	6.9	6.3	4.6	3.6	3.1	4.8
Visibility (Km)													
0700 LST	4.6	5.1	4.3	6.1	9.8	10.0	10.6	9.1	8.2	9.3	8.0	6.3	7.6
Mean	8.1	6.8	4.8	6.9	11.3	11.7	12.1	11.0	10.0	11.3	10.9	10.4	9.6
Wind (knots)													
Prevailing	NE	E	E	E	E	WSW	WSW	WSW	NE	NE	NE	NE	-
Mean speed	5.8	5.3	5.0	5.1	4.0	4.1	4.3	4.1	3.8	5.7	6.6	6.5	-
Max. speed	40NE	35E	35 SE W	80WSW	34SW	40 NE W	35S	35W	33N	33 N ENS	40NE	35NE	-
Rainfall (mm)													
Mean	3.9	12.1	45.0	74.6	184.4	266.3	231.5	307.9	294.5	63.6	3.3	0.6	1487.7
Mean rainy days	0.7	2.3	4.6	7.2	16.5	17.9	18.8	21.6	19.2	8.6	1.6	0.2	119.2
Greatest in 24 hr	21.4	31.5	73.7	82.7	74.7	106.6	167.8	156.0	176.7	64.1	12.4	7.1	176.7
Day/year	23/54	15/51	27/57	8/58	9/62	25/61	8/56	4/62	8/51	27/55	11/67	16/66	8/51
No. days with													
Haze	22.0	22.7	26.1	20.9	4.2	0.8	0.3	0.3	2.6	7.2	9.0	13.0	129.1
Fog	15.6	10.1	8.7	2.3	0.4	0.7	0.5	1.4	1.4	3.2	7.5	14.0	65.8
Hail	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.4
Thunderstorm	0.1	0.9	6.0	11.7	18.1	11.8	11.9	12.5	10.7	3.6	0.2	0.0	87.5
Squall	0.1	0.0	0.1	0.3	0.2	0.1	0.1	0.0	0.0	0.0	0.1	0.0	1.0

Remark: 1. Temperature 1953-1970
Evaporation 1957-1970

TABLE XXVI

CLIMATOLOGICAL DATA FOR THE PERIOD 1951-1970

Station KHON KAEN	Elevation of station above MSL 164.63 meters
Index Station 48 381	Height of barometer above MSL 165.41
Latitude 16° 20' N.	Height of thermometer above ground 1.50
Longitude 102° 51' E.	Height of wind vane above ground 14.50
	Height of rainguage 0.60

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Evaporation (mm)													
Mean - Piche	108.5	112.5	141.9	153.3	116.1	96.8	86.5	73.8	55.9	70.4	88.6	98.3	1184.6
- Pan	174.7	175.4	224.8	228.6	202.7	170.5	176.9	162.7	142.0	174.6	172.4	177.5	2182.8
Cloudiness (0-8)													
Mean	2.7	2.8	3.2	3.9	5.5	6.3	6.4	6.6	6.2	4.5	3.6	3.0	4.6
Visibility (Km)													
0700 LST	5.3	5.2	4.8	5.9	7.5	7.7	7.9	7.6	7.1	7.2	7.0	6.0	6.6
Mean	7.2	6.6	5.8	7.0	8.2	8.4	8.5	8.4	8.0	8.6	8.3	8.0	7.8
Wind (knots)													
Prevailing	NE	NE	NE	SW	SW	SW	SW	SW	SW	NE	NE	NE	-
Mean speed	3.6	3.3	3.8	4.0	3.9	4.1	4.6	4.0	3.1	3.8	4.1	4.0	-
Max. speed	33NE	33NW	40NE	40 E NW	47 SW WNW	39 SW W	55W	40E	33 SE SW	34NE	35N	38NE	-
Rainfall (mm)													
Mean	9.2	19.8	39.6	63.0	166.0	187.6	149.5	176.9	277.6	95.7	11.4	1.5	1197.8
Mean rainy days	1.2	3.0	4.7	6.6	14.5	14.4	15.9	17.6	18.1	9.9	1.7	0.6	108.2
Greatest in 24 hr	29.2	63.4	70.2	65.7	96.9	123.8	92.8	99.0	141.6	124.5	55.9	8.3	141.6
Day/year	24/69	3/66	12/52	6/65	10/52	12/70	26/53	14/61	8/51	26/69	8/63	20/66	8/51
No. days with													
Haze	23.2	23.7	23.2	13.0	1.6	0.1	0.1	0.5	0.9	3.6	8.3	20.8	119.0
Fog	5.6	4.1	1.8	0.9	0.1	0.0	0.1	0.3	0.3	1.0	3.8	3.5	21.5
Hail	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Thunderstorm	0.4	1.4	6.6	12.2	17.0	13.2	13.2	11.6	13.1	5.5	0.5	0.1	94.8
Squall	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Remark: Evaporation 1. Piche 1957-1967
2. Pan 1961-1970

TABLE XXVII

CLIMATOLOGICAL DATA FOR THE PERIOD 1951-1970

Station ROI ET	Elevation of station above MSL 140.00 meters
Index Station 48 405	Height of barometer above MSL 141.35
Latitude 16° 03' N.	Height of thermometer above ground 1.20
Longitude 103° 41' E.	Height of wind vane above ground 13.00
	Height of rainguage 0.65

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Evaporation (mm)													
Mean - Piche	92.8	94.4	117.3	103.1	80.6	64.1	62.3	54.1	48.1	61.0	72.7	83.4	933.9
- Pan	154.8	152.8	192.1	180.8	163.0	142.3	149.5	130.8	115.9	150.3	154.0	54.6	1840.9
Cloudiness (0-8)													
Mean	2.8	3.3	3.6	4.5	5.8	6.5	6.5	6.9	6.4	4.7	3.6	3.0	4.8
Visibility (Km)													
0700 LST	4.4	5.1	5.4	6.3	8.0	8.9	9.0	8.3	7.8	8.1	7.2	5.6	7.0
Mean	7.6	7.0	6.6	7.4	9.1	9.8	9.9	9.4	9.1	9.8	9.9	8.9	8.7
Wind (knots)													
Prevailing	E	E	E	S	S	SW	SW	SW	SW	E	E	E	-
Mean speed	4.7	4.1	4.2	4.0	4.7	4.7	4.7	4.3	3.2	3.9	4.6	4.4	-
Max. speed	24NE	33NE	34SW	36N	36S	27S SW	30S	36NE	27E SW	28S	27E	27E	-
Rainfall (mm)													
Mean	1.9	11.1	37.3	89.9	193.2	195.1	196.5	240.1	336.3	89.2	9.0	0.2	1399.8
Mean rainy days	0.7	2.1	4.2	7.4	14.6	14.5	15.4	17.5	19.0	8.4	1.7	0.3	105.8
Greatest in 24 hr	9.2	28.8	63.0	88.5	118.0	140.6	135.0	140.2	230.6	63.4	33.0	1.2	230.6
Day/year	27/54	12/56	7/61	23/51	31/70	6/55	12/65	25/63	22/64	7/62	5/64	23/59	22/64
No. days with													
Haze	24.0	23.1	37.6	23.0	9.1	1.6	0.8	0.8	2.1	10.5	16.6	23.0	162.2
Fog	8.9	4.8	2.3	3.3	2.6	0.1	0.1	0.2	0.4	0.6	2.6	6.3	32.1
Hail	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.3
Thunderstorm	0.2	0.9	4.4	8.1	13.9	7.6	8.6	10.5	8.6	4.7	0.5	0.2	68.2
Squall	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.2

Remark: 1. Temperature 1955-1970
2. Evaporation 1958-1970

TABLE XXVIII

CLIMATOLOGICAL DATA FOR THE PERIOD 1951-1970

Station UBON RATCHATHANI	
Index Station 48 407	
Latitude 15° 15' N.	
Longitude 104° 53' E.	
Elevation of station above MSL	123.00 meters
Height of barometer above MSL	128.40
Height of thermometer above ground	1.20
Height of wind vane above ground	12.30
Height of rainguage	0.74

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Evaporation (mm)													
Mean - Piche	119.8	119.1	138.1	121.6	95.3	79.7	80.3	71.7	59.9	84.3	104.9	113.3	1188.0
- Pan	191.3	192.1	237.4	226.0	194.1	176.5	182.5	168.7	151.2	191.5	199.0	195.6	2305.9
Cloudiness (0-8)													
Mean	2.8	3.1	3.6	4.5	5.8	6.4	6.4	6.7	6.4	4.9	3.7	3.1	4.0
Visibility (Km)													
0700 LST	7.9	6.5	6.0	7.1	10.0	10.9	10.3	9.7	9.4	10.7	11.3	9.9	9.0
Mean	11.3	8.8	7.6	8.6	11.1	11.7	11.4	10.9	10.8	12.4	13.3	13.1	10.9
Wind (knots)													
Prevailing	NE	NE	NE	S	S	S	W	W	W	NE	NE	NE	-
Mean speed	4.8	3.8	3.6	3.6	3.4	4.4	4.5	4.4	3.4	4.7	5.8	5.3	-
Max. speed	33NE	46NE	41N	56SW	42N SW	60W	41WSW	68S	46E	55NE	40NE	51NE	-
Rainfall (mm)													
Mean	0.8	6.9	55.6	81.4	217.3	234.9	273.2	299.3	271.5	103.0	18.7	1.5	1565.0
Mean rainy days	0.4	1.0	4.2	7.4	15.2	18.0	19.8	22.0	20.6	10.5	3.2	0.7	123.0
Greatest in 24 hr	6.4	37.0	124.1	82.1	138.5	99.5	203.9	182.8	130.3	113.4	69.5	8.2	203.9
Day/year	27/54	27/62	14/60	1/56	18/56	29/59	7/70	8/51	5/68	9/67	5/64	15/66	7/70
No. days with													
Haze	17.9	24.1	27.1	19.6	3.0	0.9	1.2	0.6	1.8	4.5	7.4	10.7	118.8
Fog	4.7	4.2	3.0	1.9	0.3	0.2	0.2	0.2	1.1	1.0	1.4	2.3	20.5
Hail	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Thunderstorm	0.0	0.7	4.7	9.9	17.9	12.4	13.3	9.6	8.8	5.7	1.6	0.1	84.7
Squall	0.1	0.0	0.2	0.2	0.1	0.3	0.3	0.4	0.1	0.1	0.0	0.0	1.5

Remark: Evaporation - Piche 1954-
- Pan 1961-1970

TABLE XXIX

CLIMATOLOGICAL DATA FOR THE PERIOD 1951-1970

Station SURIN	Elevation of station above MSL	145.00 meters
Index Station 48 432	Height of barometer above MSL	146.28
Latitude 14° 53' N.	Height of thermometer above ground	1.25
Longitude 103° 29' E.	Height of wind vane above ground	11.10
	Height of rainguage	0.66

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Evaporation (mm)													
Mean - Piche	149.3	148.0	170.6	147.9	104.9	81.7	78.6	68.8	60.0	83.4	103.4	128.3	1324.5
- Pan	193.8	191.5	235.3	223.5	204.3	182.3	190.0	164.8	142.1	181.7	180.1	183.4	2272.8
Cloudiness (0-8)													
Mean	3.6	4.0	4.3	5.3	6.2	6.7	6.7	7.0	6.8	5.6	4.6	3.9	5.4
Visibility (Km)													
0700 LST	5.8	6.1	6.0	6.8	8.0	8.8	8.8	8.5	8.3	7.8	6.9	6.0	7.3
Mean	7.8	7.2	7.2	7.7	8.6	9.0	9.1	8.9	8.8	9.2	9.0	8.7	8.4
Wind (knots)													
Prevailing	NE	NE	S	S	S	S	S	S	S	NE	NE	NE	-
Mean speed	3.5	3.3	3.5	3.5	3.5	3.8	3.8	3.5	3.1	3.8	4.0	4.4	-
Max. speed	33N	32NE	40SE	44E	40S	32SW	33Q	50WNW	33WSW	47E	33N	30NE	-
Rainfall (mm)													
Mean	2.1	10.5	32.9	86.3	191.5	152.9	199.4	200.3	267.6	133.1	22.0	2.0	1300.6
Mean rainy days	0.8	2.1	4.6	8.6	14.9	17.5	18.4	20.1	21.0	11.8	3.3	0.7	123.8
Greatest in 24 hr	12.8	57.7	40.1	108.9	106.3	114.4	97.6	94.5	102.4	132.1	39.6	19.5	132.1
Day/year	25/54	12/70	24/64	12/68	25/51	12/70	18/61	6/58	21/58	6/60	14/66	26/66	6/60
No. days with													
Haze	28.8	26.8	29.3	22.8	6.4	1.3	0.7	1.0	2.3	11.2	18.9	24.3	173.8
Fog	6.1	3.8	2.0	1.6	0.6	0.0	0.0	0.0	0.3	0.5	2.8	7.1	24.8
Hail	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Thunderstorm	0.2	1.2	6.7	10.8	16.7	10.7	11.1	10.6	10.1	6.2	1.5	0.1	85.9
Squall	0.0	0.0	0.1	0.8	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.0	1.4

Remark: Evaporation 1. Piche 1959-1970
2. Pan 1961-1970

TABLE XXX

CLIMATOLOGICAL DATA FOR THE PERIOD 1951-1970

Station NAKHON RATCHASIMA	Elevation of station above MSL 188.00 meters
Index Station 48 431	Height of barometer above MSL 189.50
Latitude 16° 58' N.	Height of thermometer above ground 1.50
Longitude 102° 07' E.	Height of wind vane above ground 12.20
	Height of rainguage 1.00

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Evaporation (mm)													
Mean - Piche	101.4	104.5	119.4	111.0	79.4	7-.7	76.4	68.9	49.7	60.4	74.4	88.5	1012.7
- Pan	147.7	156.1	197.5	194.0	175.5	173.5	168.0	159.7	134.8	139.9	135.2	138.1	1920.0
Cloudiness (0-8)													
Mean	2.9	3.4	3.8	4.5	5.7	6.3	6.4	6.7	6.4	5.2	3.9	3.1	4.9
Visibility (Km)													
0700 LST	4.1	3.8	4.2	5.5	8.0	9.4	9.3	9.3	8.3	6.7	5.3	4.3	6.5
Mean	7.2	6.3	6.3	7.6	9.5	10.3	10.0	9.9	9.3	9.4	9.0	8.3	8.6
Wind (knots)													
Prevailing	NE	NE	NE	SW	SW	SW	W	W	W	NE	NE	NE	-
Mean speed	2.7	3.0	2.9	5.1	2.8	4.7	4.1	3.9	2.6	3.0	3.3	3.2	-
Max. speed	28ENE	37E	43SSW	53S	46SE	35SE	39NW	35SE	32SE	34SE	44NE	40NE	-
Rainfall (mm)													
Mean	3.6	27.8	55.6	71.1	177.4	109.3	143.2	133.2	261.1	176.0	29.9	2.7	1190.9
Mean rainy days	1.3	3.1	6.4	8.2	16.9	14.9	17.0	16.6	19.7	12.7	3.8	1.0	121.6
Greatest in 24 hr	17.1	59.7	81.7	63.3	134.5	114.8	96.0	72.3	143.7	80.7	108.6	20.6	143.7
Day/year	26/54	23/65	28/63	4/57	14/52	27/69	20/66	27/64	12/68	7/60	9/55	3/70	12/68
No. days with													
Haze	27.2	26.3	28.3	20.6	5.8	0.7	0.9	1.6	3.1	10.5	17.4	23.8	166.2
Fog	4.8	4.6	3.8	4.4	1.9	0.4	0.4	0.2	1.4	3.5	3.2	3.7	32.3
Hail	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Thunderstorm	0.6	1.8	7.6	13.1	16.4	7.0	7.3	6.6	8.9	6.7	0.6	0.0	76.6
Squall	0.0	0.0	0.1	0.1	0.2	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.8

Remark: Evaporation Pan 1962-1970

TABLE XXXI

CLIMATOLOGICAL DATA FOR THE PERIOD 1951-1970

Station CHAIYAPHUM
Index Station 48 403
Latitude 15° 45' N.
Longitude 102° 92' E.

Elevation of station above MSL	181.00 meters
Height of barometer above MSL	183.00
Height of thermometer above ground	1.50
Height of wind vane above ground	14.50
Height of rainguage	1.00

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Evaporation (mm)													
Mean - Piche	128.4	141.0	161.7	148.9	112.7	97.0	91.5	79.5	61.3	81.0	96.9	15.9	1315.8
- Pan	No observation												
Cloudiness (0-8)													
Mean	3.0	3.2	3.6	4.3	5.6	6.4	6.6	6.8	6.6	4.9	3.8	3.3	4.8
Visibility (Km)													
0700 LST	6.0	4.9	4.9	7.7	10.4	10.0	10.1	9.7	9.2	9.4	8.3	6.2	8.1
Mean	8.0	6.4	6.1	8.6	11.0	11.5	11.0	10.8	10.1	10.9	10.9	9.8	9.6
Wind (knots)													
Prevailing	NE	E	E	W	W	W	W	W	W	NE	NE	NE	-
Mean speed	5.5	5.7	5.8	5.9	5.7	6.3	6.3	5.8	5.2	5.8	6.1	5.8	-
Max. speed	33ENE	33S	39NE/SW	39S/NW	35WSW	33S/NW	33S/SW	27NW	33S/SW	27E/SE	27S	24NE/E	
Rainfall (mm)													
Mean	3.0	12.4	53.4	78.8	159.7	143.1	163.0	134.1	293.2	100.3	18.3	0.9	1160.2
Mean rainy days	1.0	2.1	5.9	7.6	14.0	13.2	15.3	17.2	18.9	10.4	1.7	0.7	108.0
Greatest in 24 hr	13.3	49.8	65.9	95.9	141.6	93.3	149.4	91.5	158.0	119.3	67.3	4.3	158.0
Day/year	31/58	17/61	5/69	7/63	23/59	26/68	12/62	27/66	2/69	25/66	7/63	31/62	2/69
No. days with													
Haze	22.5	24.9	24.9	15.6	1.4	0.0	0.0	0.0	0.7	3.6	10.3	18.1	122.0
Fog	1.0	0.2	0.8	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.2	0.3	2.6
Hail	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.3
Thunderstorm	0.0	1.4	16.6	11.9	16.1	7.7	7.7	8.9	10.5	5.3	0.5	0.0	76.6
Squall	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Remark:
1. Data for 1954-1970
2. Pressure 1957-1970
Evaporation 1959-1970

TABLE XXXII

CLIMATOLOGICAL DATA FOR THE PERIOD 1951-1970

Station SAP MUANG	Elevation of station above MSL 282.36 meters
Index Station 48 x x x	Height of barometer above MSL 283.86
Latitude 14° 07' N.	Height of thermometer above ground 1.10
Longitude 101° 04' E.	Height of wind vane above ground 13.50
	Height of rainguage 0.80

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Evaporation (mm)													
Mean - Piche	86.2	92.4	96.8	71.1	64.7	85.2	85.7	85.2	59.1	41.6	55.9	69.6	893.5
- Pan					No observation								
Cloudiness (0-8)													
Mean	3.5	4.2	4.5	4.9	5.8	6.3	6.6	6.6	6.3	5.4	4.3	3.5	5.2
Visibility (Km)													
0700 LST	5.3	3.2	3.1	6.1	9.8	10.4	9.7	9.5	7.4	5.8	7.2	7.4	7.1
Mean	9.6	6.9	7.4	10.1	12.7	13.3	12.4	12.4	11.4	11.9	14.1	13.9	11.3
Wind (knots)													
Prevailing	NE	NE	SW	SW	SW	SW	SW	SW	SW	NE	NE	NE	-
Mean speed	3.9	3.8	3.2	2.5	2.8	5.6	6.1	5.8	3.6	3.2	3.9	3.9	-
Max. speed	22NE	23SE	27S	27NE	33E	27W	27SW	28NW	23SW	20NE	25NE	25NE	-
Rainfall (mm)													
Mean	5.3	44.7	79.9	124.8	163.0	76.3	109.3	106.9	286.2	148.5	17.7	8.9	1171.5
Mean rainy days	1.4	4.2	7.1	11.7	15.3	13.1	16.5	15.6	17.3	13.7	3.3	1.0	120.2
Greatest in 24 hr	15.8	75.8	111.3	78.3	74.6	76.5	54.7	53.2	195.4	117.8	24.7	45.6	195.4
Day/year	26/66	2/66	3/58	23/68	27/57	20/60	12/62	14/69	28/59	6/57	14/56	17/66	28/59
No. days with													
Haze	19.6	19.2	22.3	16.5	9.6	12.1	12.9	11.5	11.2	10.2	7.5	10.8	163.4
Fog	12.2	16.3	15.3	8.6	4.3	1.4	2.2	3.2	5.8	11.7	11.2	11.7	103.9
Hail	0.0	0.1	0.3	0.7	0.1	0.1	0.1	0.0	0.0	0.0	0.5	0.0	1.9
Thunderstorm	0.8	3.6	10.7	17.3	17.3	7.1	5.8	7.1	7.8	9.3	1.5	0.4	88.7
Squall	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1

Remark: Data for 1956-1970

TABLE XXXIII

CLIMATOLOGICAL DATA FOR THE PERIOD 1951-1970

Station UDON THANI	Elevation of station above MSL 176.98 meters
Index Station 48 354	Height of barometer above MSL 182.05
Latitude 17° 26' N.	Height of thermometer above ground 1.50
Longitude 102° 46' E.	Height of wind vane above ground 17.50
	Height of rainguage 0.70

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Evaporation (mm)													
Mean - Piche	89.5	95.1	122.8	116.3	79.3	61.2	63.2	53.9	48.8	70.0	76.6	84.6	961.3
- Pan					No observation								
Cloudiness (0-8)													
Mean	2.4	2.7	3.1	4.0	5.8	6.6	6.6	6.9	6.2	4.3	3.4	2.8	4.6
Visibility (Km)													
0700 LST	2.7	2.6	2.6	4.2	6.9	7.6	8.1	7.6	7.3	6.3	4.7	3.6	5.4
Mean	5.7	4.6	4.3	6.0	9.0	9.4	9.7	9.5	9.6	9.5	9.0	7.4	7.8
Wind (knots)													
Prevailing	E	E	E	SE	SE	S	S	S	E	E	NE	E	-
Mean speed	3.1	3.4	3.5	3.7	3.5	3.3	3.6	3.3	3.2	3.1	2.9	3.0	-
Max. speed	30 W	33 NE SW	53 NW	67 WSW	51 SW	52 SW	42 NNW	44 W	43 E	43 SE	27 NE	27 E	-
Rainfall (mm)													
Mean	8.3	21.6	36.9	75.9	226.0	267.6	221.7	275.2	312.5	82.7	8.9	0.3	1537.6
Mean rainy days	1.4	2.0	5.2	7.5	18.0	18.5	19.6	20.3	20.6	8.2	1.6	0.3	123.2
Greatest in 24 hr	26.4	125.1	46.3	76.1	90.6	153.6	98.1	105.4	155.0	94.5	65.7	2.8	155.0
Day/year	11/51	10/64	1/60	12/70	14/52	12/67	14/67	21/65	25/52	13/60	8/63	2/54	25/52
No. days with													
Haze	26.9	26.4	28.8	24.4	7.9	2.5	1.4	1.0	2.4	11.5	18.6	24.2	176.6
Fog	1.4	1.9	1.8	0.2	1.0	0.2	0.1	0.3	0.8	1.7	0.9	0.8	11.1
Hail	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Thunderstorm	0.4	0.8	5.1	10.3	19.2	14.2	11.8	10.6	10.6	3.3	0.3	0.0	86.6
Squall	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.4

TABLE XXXIV

ANNUAL RAINFALL (mm) IN NORTHEASTERN THAILAND

Station No.	Year / Name	1962	1963	1964	1965	1966	1967	1968	1969	1970	Average
1	Chum Phae	1236	1133	1040	641	1382	911	661	1112	1045	1018
2	Khon Kaen	1232	1337	1224	921	1366	931	1144	1295	1347	1200
3	Loei	1007	1129	1254	1099	1185	1274	917	1147	1490	1167
4	Nong Rong	1265	1125	973	1527	1788	1227	937	1267	1116	1247
5	Phayakkaphum Phisai	1615	1383	979	1222	2020	1064	1413	1158	1221	1342
6	Phon	1632	1108	988	936	1608	947	672	1497	1151	1171
7	Roi Et	1670	1299	1697	1213	1865	1339	1365	1395	1162	1445
8	Sakol Nakorn	–	1695	1489	1348	1446	1408	1188	1541	1841	1495
9	Sawang Dandin	1302	1764	1289	1533	–	–	–	1296	2015	1533
10	Surin	1506	1303	1027	1275	1627	1168	1071	1147	1415	1282
11	Korat	1354	1358	1263	1078	1318	920	1064	1126	–	1185
12	Ubon	2040	1520	1628	1297	2258	1297	1142	1623	1751	1617
13	Sisaket	1921	1481	840	1339	2064	1002	629	1145	1331	1306
14	Mukdahan	–	–	1605	1516	1663	1170	1312	1379	1401	1435
15	Kuchinarai	1254	1142	1212	1444	1635	1002	1195	1647	1458	1332
16	Nam Pung	1302	1601	1519	1369	1535	1289	–	–	–	1436
17	Ban Nong Meg	–	1708	–	–	1892	1462	–	2306	–	1842
18	Det Udom	1207	1504	–	1568	–	1450	1463	1725	1622	1506
19	Ban Song Khon	–	–	–	–	1624	801	1258	619	1340	1128
20	Dan Sai	–	–	–	–	–	953	1087	1499	1659	1300
21	Ban Tha Kok Daeng	–	–	–	–	–	1790	1780	1776	–	1782
22	Khong Chiam	–	–	–	–	–	1934	1707	1934	2044	1900
23	Lam Dom Noi Dam Site	–	–	–	–	–	–	1839	2039	2166	2015
24	Kham Pa Lai	–	–	–	–	–	–	1544	1267	1347	1386

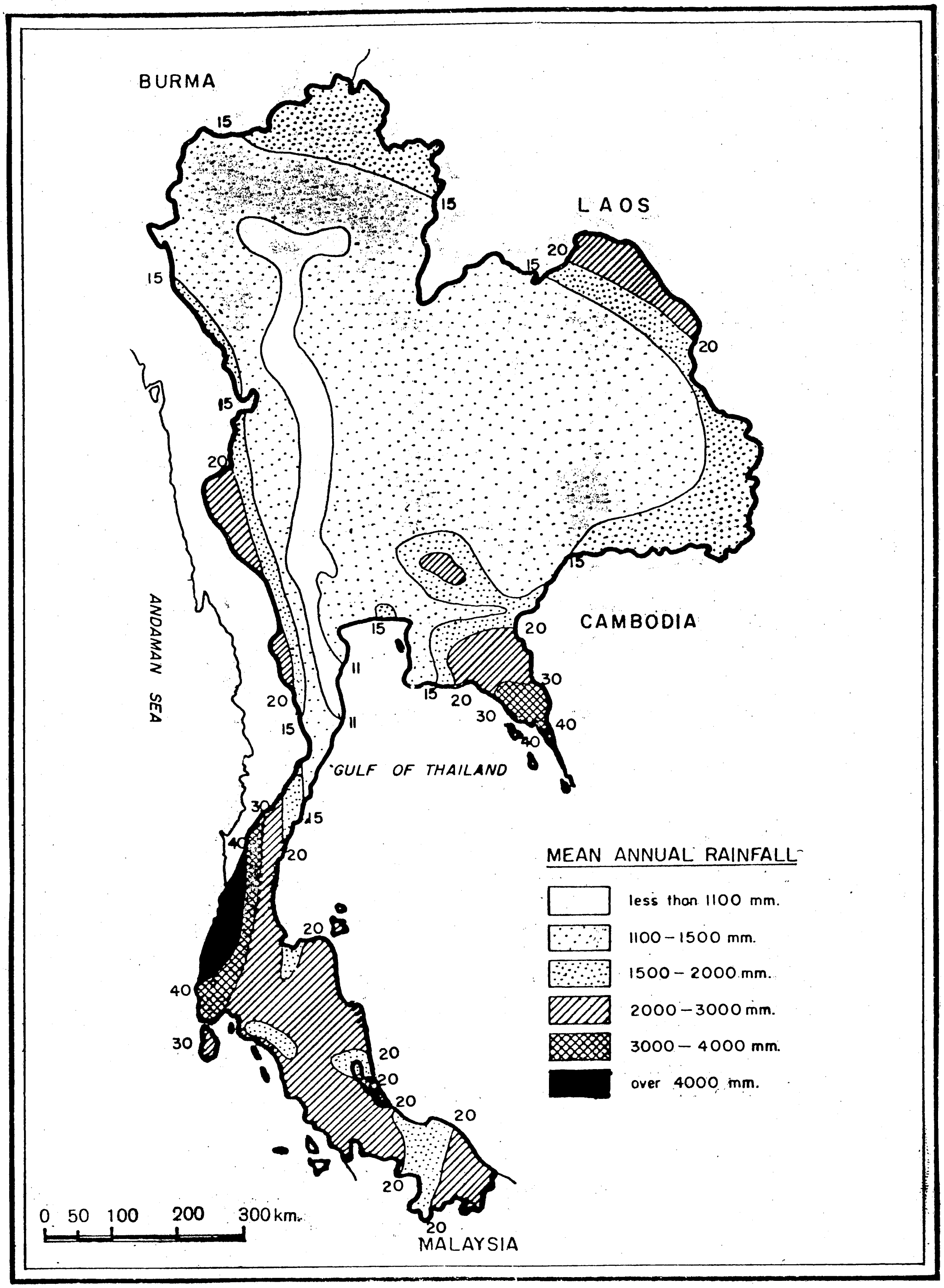


Figure 16. Isohyet Map of Thailand

APPENDIX B

LIST OF FLOOD PEAK DATA AND LOG PEARSON TYPE III DISTRIBUTION OF 38 DRAINAGE BASINS IN NORTHEASTERN THAILAND

MAE NAM CHEE AT YASOTHORN NO. OF ITEMS = 23 STATION 0- 0. 1 CODE

D A T A U S E D I N C A L C U L A T I O N S

1920.000	1490.000	1450.000	1370.000	1310.000	1290.000	1080.000	1070.000	943.000	943.000
937.000	928.000	862.000	815.000	804.000	796.000	752.000	1370.000	1010.000	929.000
828.000	919.000	516.000							

A N N U A L F L O O D S T A T I S T I C S

	LOGS	
MEAN=	3.007	1057.9
STANDARD DEVIATION=	0.125	313.6
SKEWNESS=	0.097	0.974
STANDARD ERROR OF SKEWNESS=	0.481	

L O G - P E A R S O N T Y P E I I I C A L C U L A T I O N S

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES	
0.9900	1.01	532.432	
0.9500	1.05	639.384	
0.9000	1.11	706.132	
0.8000	1.25	797.635	
0.5000	2.00	1012.027	
0.2000	5.00	1292.448	
0.1000	10.00	1472.591	
0.0400	25.00	1695.831	
0.0200	50.00	1859.777	*** R.I.> 2N
0.0100	100.00	2022.254	*** R.I.> 2N
0.0050	200.00	2184.704	*** R.I.> 2N
0.0020	500.00	2401.074	*** R.I.> 2N

NAM MAN AT DAN SAI NO. OF ITEMS = 7 STATION 0- 0. 2 CODE

D A T A U S E D I N C A L C U L A T I O N S

30.000	21.000	45.000	72.000	33.000	49.000	39.000

A N N U A L F L O O D S T A T I S T I C S

	LOGS	
MEAN=	1.587	41.3
STANDARD DEVIATION=	0.171	16.5
SKEWNESS=	0.041	0.997
STANDARD ERROR OF SKEWNESS=	0.794	

L O G - P E A R S O N T Y P E I I I C A L C U L A T I O N S

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES	
0.9900	1.01	15.668	
0.9500	1.05	20.334	
0.9000	1.11	23.389	
0.8000	1.25	27.736	
0.5000	2.00	38.540	
0.2000	5.00	53.760	
0.1000	10.00	64.074	
0.0400	25.00	77.354	*** R.I.> 2N
0.0200	50.00	87.419	*** R.I.> 2N
0.0100	100.00	97.629	*** R.I.> 2N
0.0050	200.00	108.054	*** R.I.> 2N
0.0020	500.00	122.248	*** R.I.> 2N

NAM SAN AT DAM SITE NO. OF ITEMS = 10 STATION 0- 0. 3 CODE

DATA USED IN CALCULATIONS

176.000	98.000	86.000	131.000	90.000	80.000	261.000	91.000	101.000	147.000

ANNUAL FLOOD STATISTICS

	LOGS	
MEAN=	2.069	126.1
STANDARD DEVIATION=	0.165	56.6
SKEWNESS=	1.167	1.760
STANDARD ERROR OF SKEWNESS=	0.687	

LOG-PEARSON TYPE III CALCULATIONS

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES	
0.9900	1.01	67.045	
0.9500	1.05	72.801	
0.9000	1.11	77.432	
0.8000	1.25	85.082	
0.5000	2.00	109.132	
0.2000	5.00	155.206	
0.1000	10.00	195.234	
0.0400	25.00	258.604	*** R.I.> 2N
0.0200	50.00	316.569	*** R.I.> 2N
0.0100	100.00	385.156	*** R.I.> 2N
0.0050	200.00	466.425	*** R.I.> 2N
0.0020	500.00	597.450	*** R.I.> 2N

NAM HEUNG AT BAN PAK HUAI NO. OF ITEMS = 7 STATION 0- 0. 4 CODE

DATA USED IN CALCULATIONS

537.000	216.000	314.000	747.000	267.000	319.000	591.000

ANNUAL FLOOD STATISTICS

	LOGS	
MEAN=	2.591	427.3
STANDARD DEVIATION=	0.200	198.3
SKEWNESS=	0.240	0.662
STANDARD ERROR OF SKEWNESS=	0.794	

LOG-PEARSON TYPE III CALCULATIONS

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES	
0.9900	1.01	144.680	
0.9500	1.05	188.617	
0.9000	1.11	218.698	
0.8000	1.25	263.259	
0.5000	2.00	382.759	
0.2000	5.00	571.237	
0.1000	10.00	711.766	
0.0400	25.00	907.307	*** R.I.> 2N
0.0200	50.00	1066.172	*** R.I.> 2N
0.0100	100.00	1236.490	*** R.I.> 2N
0.0050	200.00	1419.746	*** R.I.> 2N
0.0020	500.00	1684.159	*** R.I.> 2N

NAM LOEI AT WANG SAPHUNG   NO. OF ITEMS =   5   STATION 0-   0. 5   CODE

D A T A   U S E D   I N   C A L C U L A T I O N S

135.000	171.000	272.000	282.000	913.000

A N N U A L   F L O O D   S T A T I S T I C S

	LOGS	
MEAN=	2.442	354.6
STANDARD DEVIATION=	0.320	318.5
SKEWNESS=	1.275	2.016
STANDARD ERROR OF SKEWNESS=	0.913	

L O G - P E A R S O N   T Y P E   I I I   C A L C U L A T I O N S

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES	
0.9900	1.01	98.581	
0.9500	1.05	112.923	
0.9000	1.11	125.708	
0.8000	1.25	148.920	
0.5000	2.00	237.472	
0.2000	5.00	470.952	
0.1000	10.00	742.011	*** R.I.> 2N
0.0400	25.00	1302.608	*** R.I.> 2N
0.0200	50.00	1958.543	*** R.I.> 2N
0.0100	100.00	2913.868	*** R.I.> 2N
0.0050	200.00	4300.645	*** R.I.> 2N
0.0020	500.00	7127.289	*** R.I.> 2N

NAM SONGKRAM AT BAN THA KOK DAENG   NO. OF ITEMS =   10   STATION 0-   0. 6   CODE

D A T A   U S E D   I N   C A L C U L A T I O N S

330.000	421.000	582.000	398.000	380.000	425.000	644.000	418.000	430.000	527.000

A N N U A L   F L O O D   S T A T I S T I C S

	LOGS	
MEAN=	2.650	455.5
STANDARD DEVIATION=	0.089	97.5
SKEWNESS=	0.615	0.951
STANDARD ERROR OF SKEWNESS=	0.687	

L O G - P E A R S O N   T Y P E   I I I   C A L C U L A T I O N S

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES	
0.9900	1.01	305.209	
0.9500	1.05	332.270	
0.9000	1.11	349.983	
0.8000	1.25	375.150	
0.5000	2.00	437.605	
0.2000	5.00	525.748	
0.1000	10.00	585.878	
0.0400	25.00	664.010	*** R.I.> 2N
0.0200	50.00	723.871	*** R.I.> 2N
0.0100	100.00	785.225	*** R.I.> 2N
0.0050	200.00	848.573	*** R.I.> 2N
0.0020	500.00	936.009	*** R.I.> 2N

NAN PUNG AT BAN THAM HAI BRIDGE NO. OF ITEMS = 10 STATION 0- 0. 7 CODE

D A T A U S E D I N C A L C U L A T I O N S

118.000	68.000	150.000	88.000	110.000	178.000	147.000	190.000	162.000	24.000

A N N U A L F L O O D S T A T I S T I C S

	LOGS	
MEAN=	2.035	123.5
STANDARD DEVIATION=	0.269	52.3
SKEWNESS=	-1.814	-0.641
STANDARD ERROR OF SKEWNESS=	0.687	

L O G - P E A R S O N T Y P E I I I C A L C U L A T I O N S

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES	
0.9900	1.01	12.319	
0.9500	1.05	31.715	
0.9000	1.11	47.930	
0.8000	1.25	72.878	
0.5000	2.00	129.293	
0.2000	5.00	177.823	
0.1000	10.00	194.461	
0.0400	25.00	205.438	*** R.I.> 2N
0.0200	50.00	209.587	*** R.I.> 2N
0.0100	100.00	211.915	*** R.I.> 2N
0.0050	200.00	213.226	*** R.I.> 2N
0.0020	500.00	214.128	*** R.I.> 2N

HUAI BANG SAI AT BAN NONG AEK BRIDGE (BACK WATER) NO. OF ITEMS = 11 STATION 0- 0. 8 CODE

D A T A U S E D I N C A L C U L A T I O N S

410.000	482.000	514.000	319.000	189.000	152.000	234.000	241.000	116.000	176.000
280.000									

A N N U A L F L O O D S T A T I S T I C S

	LOGS	
MEAN=	2.407	283.0
STANDARD DEVIATION=	0.209	134.1
SKEWNESS=	0.009	0.666
STANDARD ERROR OF SKEWNESS=	0.661	

L O G - P E A R S O N T Y P E I I I C A L C U L A T I O N S

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES	
0.9900	1.01	83.780	
0.9500	1.05	115.998	
0.9000	1.11	138.007	
0.8000	1.25	170.362	
0.5000	2.00	255.096	
0.2000	5.00	382.364	
0.1000	10.00	472.646	
0.0400	25.00	592.711	*** R.I.> 2N
0.0200	50.00	686.157	*** R.I.> 2N
0.0100	100.00	782.823	*** R.I.> 2N
0.0050	200.00	883.267	*** R.I.> 2N
0.0020	500.00	1022.539	*** R.I.> 2N

HUAI BANG I AT BAN KAM SOI   NO. OF ITEMS = 10   STATION 0- 0. 9   CODE

D A T A   U S E D   I N   C A L C U L A T I O N S

180.000	146.000	115.000	101.000	142.000	173.000	164.000	191.000	160.000	95.000

A N N U A L   F L O O D   S T A T I S T I C S

	LOGS	
MEAN=	2.155	146.7
STANDARD DEVIATION=	0.106	33.4
SKEWNESS=	-0.691	-0.433
STANDARD ERROR OF SKEWNESS=	0.687	

L O G - P E A R S O N   T Y P E   I I I   C A L C U L A T I O N S

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES
0.9900	1.01	71.683
0.9500	1.05	91.605
0.9000	1.11	103.144
0.8000	1.25	117.786
0.5000	2.00	147.039
0.2000	5.00	176.394
0.1000	10.00	191.157
0.0400	25.00	206.101 *** R.I.> 2N
0.0200	50.00	215.202 *** R.I.> 2N
0.0100	100.00	222.960 *** R.I.> 2N
0.0050	200.00	229.677 *** R.I.> 2N
0.0020	500.00	237.295 *** R.I.> 2N

LAM DOM YAI AT DET UDOM   NO. OF ITEMS = 11   STATION 0- 0.10   CODE

D A T A   U S E D   I N   C A L C U L A T I O N S

273.000	296.000	331.000	492.000	293.000	433.000	246.000	332.000	270.000	1150.000
135.000									

A N N U A L   F L O O D   S T A T I S T I C S

	LOGS	
MEAN=	2.523	386.5
STANDARD DEVIATION=	0.229	269.9
SKEWNESS=	0.984	2.627
STANDARD ERROR OF SKEWNESS=	0.661	

L O G - P E A R S O N   T Y P E   I I I   C A L C U L A T I O N S

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES
0.9900	1.01	143.617
0.9500	1.05	166.203
0.9000	1.11	183.887
0.8000	1.25	212.978
0.5000	2.00	305.481
0.2000	5.00	497.937
0.1000	10.00	676.276
0.0400	25.00	977.379 *** R.I.> 2N
0.0200	50.00	1269.574 *** R.I.> 2N
0.0100	100.00	1632.594 *** R.I.> 2N
0.0050	200.00	2083.431 *** R.I.> 2N
0.0020	500.00	2849.940 *** R.I.> 2N

LAM DOM NOI AT SE FALL NO. OF ITEMS = 8 STATION 0- 0.11 CODE

D A T A   U S E D   I N   C A L C U L A T I O N S

652.000	408.000	432.000	416.000	351.000	356.000	691.000	348.000

A N N U A L   F L O O D   S T A T I S T I C S

	LOGS	
MEAN=	2.645	456.8
STANDARD DEVIATION=	0.118	136.7
SKEWNESS=	1.076	1.238
STANDARD ERROR OF SKEWNESS=	0.752	

L O G - P E A R S O N   T Y P E   I I I   C A L C U L A T I O N S

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES
0.9900	1.01	290.566
0.9500	1.05	310.678
0.9000	1.11	325.994
0.8000	1.25	350.201
0.5000	2.00	420.594
0.2000	5.00	540.879
0.1000	10.00	635.528
0.0400	25.00	772.982 *** R.I.> 2N
0.0200	50.00	889.132 *** R.I.> 2N
0.0100	100.00	1017.832 *** R.I.> 2N
0.0050	200.00	1160.925 *** R.I.> 2N
0.0020	500.00	1375.463 *** R.I.> 2N

NAM MUN AT UBOL NO. OF ITEMS = 30 STATION 0- 0.12 CODE

D A T A   U S E D   I N   C A L C U L A T I O N S

2470.000	3110.000	2210.000	2940.000	3300.000	3690.000	4790.000	2680.000	2150.000	1970.000
3040.000	1020.000	2710.000	2050.000	2880.000	3130.000	3130.000	3720.000	3930.000	1930.000
3620.000	1240.000	5540.000	2480.000	2420.000	2350.000	2260.000	2180.000	2850.000	1130.000

A N N U A L   F L O O D   S T A T I S T I C S

	LOGS	
MEAN=	3.413	2764.0
STANDARD DEVIATION=	0.165	984.2
SKEWNESS=	-0.640	0.712
STANDARD ERROR OF SKEWNESS=	0.427	

L O G - P E A R S O N   T Y P E   I I I   C A L C U L A T I O N S

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES
0.9900	1.01	902.031
0.9500	1.05	1306.355
0.9000	1.11	1564.357
0.8000	1.25	1915.828
0.5000	2.00	2696.690
0.2000	5.00	3585.268
0.1000	10.00	4073.103
0.0400	25.00	4596.555
0.0200	50.00	4930.816
0.0100	100.00	5225.691 *** R.I.> 2N
0.0050	200.00	5488.797 *** R.I.> 2N
0.0020	500.00	5796.727 *** R.I.> 2N

NAM KAM AT NAKAE NAKORN PHANOM   NO. OF ITEMS = 10   STATION 0- 0.14 CODE

DATA USED IN CALCULATIONS

143.000	91.000	136.000	70.000	146.000	166.000	175.000	212.000	122.000	83.000

ANNUAL FLOOD STATISTICS

	LOGS	
MEAN=	2.108	134.9
STANDARD DEVIATION=	0.150	43.7
SKEWNESS=	-0.456	0.152
STANDARD ERROR OF SKEWNESS=	0.687	

LOG-PEARSON TYPE III CALCULATIONS

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES
0.9900	1.01	51.164
0.9500	1.05	69.634
0.9000	1.11	81.180
0.8000	1.25	96.789
0.5000	2.00	131.569
0.2000	5.00	172.316
0.1000	10.00	195.624
0.0400	25.00	221.672 *** R.I.> 2N
0.0200	50.00	239.004 *** R.I.> 2N
0.0100	100.00	254.839 *** R.I.> 2N
0.0050	200.00	269.470 *** R.I.> 2N
0.0020	500.00	287.293 *** R.I.> 2N

LAM TA KHONG AT KHAO YAI   NO. OF ITEMS = 9   STATION 0- 0.15 CODE

DATA USED IN CALCULATIONS

44.000	43.000	23.000	14.000	38.000	18.000	11.000	37.000	25.000

ANNUAL FLOOD STATISTICS

	LOGS	
MEAN=	1.403	28.1
STANDARD DEVIATION=	0.221	12.7
SKEWNESS=	-0.469	-0.003
STANDARD ERROR OF SKEWNESS=	0.717	

LOG-PEARSON TYPE III CALCULATIONS

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES
0.9900	1.01	6.531
0.9500	1.05	10.304
0.9000	1.11	12.925
0.8000	1.25	16.752
0.5000	2.00	26.317
0.2000	5.00	39.084
0.1000	10.00	47.044
0.0400	25.00	56.444 *** R.I.> 2N
0.0200	50.00	62.972 *** R.I.> 2N
0.0100	100.00	69.115 *** R.I.> 2N
0.0050	200.00	74.936 *** R.I.> 2N
0.0020	500.00	82.204 *** R.I.> 2N

LAM TA KHONG AT BAN BUNG TOEI　　NO. OF ITEMS = 10　　STATION 0- 0.16　　CODE

D A T A   U S E D   I N   C A L C U L A T I O N S

78.000	87.000	75.000	84.000	21.000	123.000	34.000	26.000	197.000	47.000

A N N U A L   F L O O D   S T A T I S T I C S

	LOGS	
MEAN=	1.796	77.2
STANDARD DEVIATION=	0.306	52.9
SKEWNESS=	-0.123	1.313
STANDARD ERROR OF SKEWNESS=	0.687	

L O G - P E A R S O N   T Y P E   I I I   C A L C U L A T I O N S

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES	
0.9900	1.01	11.385	
0.9500	1.05	19.140	
0.9000	1.11	25.104	
0.8000	1.25	34.686	
0.5000	2.00	63.368	
0.2000	5.00	113.429	
0.1000	10.00	152.543	
0.0400	25.00	207.963	*** R.I.> 2N
0.0200	50.00	253.226	*** R.I.> 2N
0.0100	100.00	301.637	*** R.I.> 2N
0.0050	200.00	353.373	*** R.I.> 2N
0.0020	500.00	427.120	*** R.I.> 2N

LAM DOM YAI AT BAN FANG PHE　　NO. OF ITEMS = 5　　STATION 0- 0.17　　CODE

D A T A   U S E D   I N   C A L C U L A T I O N S

200.000	207.000	186.000	346.000	61.000

A N N U A L   F L O O D   S T A T I S T I C S

	LOGS	
MEAN=	2.242	200.0
STANDARD DEVIATION=	0.277	101.1
SKEWNESS=	-1.347	0.171
STANDARD ERROR OF SKEWNESS=	0.913	

L O G - P E A R S O N   T Y P E   I I I   C A L C U L A T I O N S

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES	
0.9900	1.01	22.158	
0.9500	1.05	51.006	
0.9000	1.11	74.442	
0.8000	1.25	110.897	
0.5000	2.00	200.612	
0.2000	5.00	297.490	
0.1000	10.00	341.640	*** R.I.> 2N
0.0400	25.00	380.266	*** R.I.> 2N
0.0200	50.00	399.700	*** R.I.> 2N
0.0100	100.00	413.619	*** R.I.> 2N
0.0050	200.00	423.664	*** R.I.> 2N
0.0020	500.00	432.839	*** R.I.> 2N

NAM CHI AT BAN KOK UBON   NO. OF ITEMS = 8   STATION 0- 0.18   CODE

DATA USED IN CALCULATIONS

633.000	586.000	142.000	803.000	635.000	531.000	216.000	321.000

ANNUAL FLOOD STATISTICS

	LOGS	
MEAN=	2.624	483.4
STANDARD DEVIATION=	0.265	231.4
SKEWNESS=	-0.957	-0.346
STANDARD ERROR OF SKEWNESS=	0.752	

LOG-PEARSON TYPE III CALCULATIONS

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES	
0.9900	1.01	67.519	
0.9500	1.05	134.348	
0.9000	1.11	185.664	
0.8000	1.25	264.228	
0.5000	2.00	463.557	
0.2000	5.00	709.192	
0.1000	10.00	843.249	
0.0400	25.00	981.042	*** R.I.> 2N
0.0200	50.00	1063.964	*** R.I.> 2N
0.0100	100.00	1132.962	*** R.I.> 2N
0.0050	200.00	1190.749	*** R.I.> 2N
0.0020	500.00	1253.347	*** R.I.> 2N

NAM MUN AT PAK MUN   NO. OF ITEMS = 7   STATION 0- 0.19   CODE

DATA USED IN CALCULATIONS

6650.000	2930.000	3150.000	4880.000	3220.000	3320.000	1570.000

ANNUAL FLOOD STATISTICS

	LOGS	
MEAN=	3.529	3674.3
STANDARD DEVIATION=	0.195	1627.7
SKEWNESS=	-0.241	0.979
STANDARD ERROR OF SKEWNESS=	0.794	

LOG-PEARSON TYPE III CALCULATIONS

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES	
0.9900	1.01	1099.132	
0.9500	1.05	1567.969	
0.9000	1.11	1881.317	
0.8000	1.25	2330.248	
0.5000	2.00	3440.104	
0.2000	5.00	4950.703	
0.1000	10.00	5929.117	
0.0400	25.00	7133.707	*** R.I.> 2N
0.0200	50.00	8007.145	*** R.I.> 2N
0.0100	100.00	8860.406	*** R.I.> 2N
0.0050	200.00	9699.758	*** R.I.> 2N
0.0020	500.00	10794.652	*** R.I.> 2N

LAM CHOEN AT BAN SONG KORN NO. OF ITEMS = 6 STATION 0- 0.20 CODE

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D A T A   U S E D   I N   C A L C U L A T I O N S

252.000	242.000	151.000	175.000	81.000	79.000

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A N N U A L   F L O O D   S T A T I S T I C S

	LOGS	
MEAN=	2.169	163.3
STANDARD DEVIATION=	0.222	75.1
SKEWNESS=	-0.401	0.018
STANDARD ERROR OF SKEWNESS=	0.845	

L O G - P E A R S O N   T Y P E   I I I   C A L C U L A T I O N S

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES
0.9900	1.01	38.644
0.9500	1.05	60.194
0.9000	1.11	75.174
0.8000	1.25	97.135
0.5000	2.00	152.661
0.2000	5.00	228.581
0.1000	10.00	277.086
0.0400	25.00	335.616 *** R.I.> 2N
0.0200	50.00	377.102 *** R.I.> 2N
0.0100	100.00	416.798 *** R.I.> 2N
0.0050	200.00	455.017 *** R.I.> 2N
0.0020	500.00	503.611 *** R.I.> 2N

HUAI MONG AT BAN PHU UDON THANI NO. OF ITEMS = 18 STATION 0- 0.21 CODE

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D A T A   U S E D   I N   C A L C U L A T I O N S

33.000	185.000	97.000	211.000	327.000	118.000	75.000	93.000	170.000	172.000
180.000	84.000	41.000	309.000	127.000	109.000	168.000	331.000		

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A N N U A L   F L O O D   S T A T I S T I C S

	LOGS	
MEAN=	2.120	157.2
STANDARD DEVIATION=	0.281	90.9
SKEWNESS=	-0.548	0.769
STANDARD ERROR OF SKEWNESS=	0.536	

L O G - P E A R S O N   T Y P E   I I I   C A L C U L A T I O N S

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES
0.9900	1.01	22.762
0.9500	1.05	41.611
0.9000	1.11	55.992
0.8000	1.25	78.428
0.5000	2.00	139.821
0.2000	5.00	229.333
0.1000	10.00	287.835
0.0400	25.00	358.560
0.0200	50.00	408.345 *** R.I.> 2N
0.0100	100.00	455.486 *** R.I.> 2N
0.0050	200.00	500.278 *** R.I.> 2N
0.0020	500.00	556.223 *** R.I.> 2N

NAM PHUNG AT BAN CHUN PEN SAKHON NAKORN NO. OF ITEMS = 9 STATION 0- 0.22 CODE

DATA USED IN CALCULATIONS

157.000	82.000	122.000	72.000	50.000	82.000	66.000	75.000	53.000

ANNUAL FLOOD STATISTICS

	LOGS	
MEAN=	1.898	84.3
STANDARD DEVIATION=	0.159	34.4
SKEWNESS=	0.765	1.414
STANDARD ERROR OF SKEWNESS=	0.717	

LOG-PEARSON TYPE III CALCULATIONS

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES
0.9900	1.01	41.532
0.9500	1.05	47.349
0.9000	1.11	51.492
0.8000	1.25	57.805
0.5000	2.00	75.546
0.2000	5.00	105.458
0.1000	10.00	129.108
0.0400	25.00	163.779 *** R.I.> 2N
0.0200	50.00	193.374 *** R.I.> 2N
0.0100	100.00	226.457 *** R.I.> 2N
0.0050	200.00	263.554 *** R.I.> 2N
0.0020	500.00	319.711 *** R.I.> 2N

NAM YANG AT BAN NONG SAENG THA ROI ET (E.33A) NO. OF ITEMS = 14 STATION 0- 0.23 CODE

DATA USED IN CALCULATIONS

500.000	235.000	235.000	337.000	179.000	315.000	248.000	371.000	297.000	304.000
360.000	299.000	148.000	429.000						

ANNUAL FLOOD STATISTICS

	LOGS	
MEAN=	2.462	304.1
STANDARD DEVIATION=	0.142	94.3
SKEWNESS=	-0.485	0.363
STANDARD ERROR OF SKEWNESS=	0.597	

LOG-PEARSON TYPE III CALCULATIONS

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES
0.9900	1.01	120.982
0.9500	1.05	162.587
0.9000	1.11	188.257
0.8000	1.25	222.593
0.5000	2.00	297.749
0.2000	5.00	383.688
0.1000	10.00	431.904
0.0400	25.00	485.013
0.0200	50.00	519.904 *** R.I.> 2N
0.0100	100.00	551.474 *** R.I.> 2N
0.0050	200.00	580.380 *** R.I.> 2N
0.0020	500.00	615.245 *** R.I.> 2N

CHEE RIVER AT BAN NONG OH CHAIYAPHUME (E 32) NO. OF ITEMS = 15 STATION 0- 0.24 CODE

DATA USED IN CALCULATIONS

279.000	247.000	1509.000	473.000	1076.000	169.000	390.000	294.000	178.000	777.000
188.000	203.000	242.000	207.000	169.000					

ANNUAL FLOOD STATISTICS

	LOGS	
MEAN=	2.514	428.1
STANDARD DEVIATION=	0.301	393.2
SKEWNESS=	1.210	2.001
STANDARD ERROR OF SKEWNESS=	0.580	

LOG-PEARSON TYPE III CALCULATIONS

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES
0.9900	1.01	120.115
0.9500	1.05	138.301
0.9000	1.11	154.044
0.8000	1.25	182.021
0.5000	2.00	284.942
0.2000	5.00	542.160
0.1000	10.00	827.003
0.0400	25.00	1390.284
0.0200	50.00	2022.499 *** R.I.> 2N
0.0100	100.00	2910.902 *** R.I.> 2N
0.0050	200.00	4155.676 *** R.I.> 2N
0.0020	500.00	6589.715 *** R.I.> 2N

HUAI SAMRAN HIGHWAY BRIDGE SISAKET (M.9) NO. OF ITEMS = 21 STATION 0- 0.25 CODE

DATA USED IN CALCULATIONS

214.000	325.000	426.000	494.000	418.000	728.000	126.000	254.000	18.000	313.000
15.000	54.000	760.000	212.000	225.000	250.000	455.000	126.000	332.000	27.000
126.000									

ANNUAL FLOOD STATISTICS

	LOGS	
MEAN=	2.266	280.9
STANDARD DEVIATION=	0.492	211.2
SKEWNESS=	-1.092	0.840
STANDARD ERROR OF SKEWNESS=	0.501	

LOG-PEARSON TYPE III CALCULATIONS

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES
0.9900	1.01	5.640
0.9500	1.05	21.657
0.9000	1.11	40.434
0.8000	1.25	79.243
0.5000	2.00	225.674
0.2000	5.00	481.692
0.1000	10.00	646.874
0.0400	25.00	828.445
0.0200	50.00	940.772 *** R.I.> 2N
0.0100	100.00	1034.475 *** R.I.> 2N
0.0050	200.00	1112.219 *** R.I.> 2N
0.0020	500.00	1194.607 *** R.I.> 2N

.AM PHRA PHLOENG AT PAK THONG CHAI NAKORN RATCHSIMA NO. OF ITEMS = 8 STATION 0- 0.26 CODE

DATA USED IN CALCULATIONS

184.000	122.000	479.000	304.000	17.000	121.000	97.000	217.000

ANNUAL FLOOD STATISTICS

	LOGS	
MEAN=	2.144	192.6
STANDARD DEVIATION=	0.434	144.0
SKEWNESS=	-1.311	1.139
STANDARD ERROR OF SKEWNESS=	0.752	

LOG-PEARSON TYPE III CALCULATIONS

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES
0.9900	1.01	5.575
0.9500	1.05	20.287
0.9000	1.11	36.508
0.8000	1.25	67.952
0.5000	2.00	172.177
0.2000	5.00	321.881
0.1000	10.00	402.640
0.0400	25.00	479.157 *** R.I.> 2N
0.0200	50.00	520.337 *** R.I.> 2N
0.0100	100.00	551.065 *** R.I.> 2N
0.0050	200.00	573.973 *** R.I.> 2N
0.0020	500.00	595.536 *** R.I.> 2N

MUNE RIVER AT THA CHANG (M.2) NO. OF ITEMS = 23 STATION 0- 0.27 CODE

DATA USED IN CALCULATIONS

773.000	236.000	800.000	305.000	151.000	180.000	980.000	175.000	992.000	122.000
1136.000	49.000	280.000	220.000	271.000	298.000	182.000	95.000	10.000	234.000
64.000	55.000	234.000							

ANNUAL FLOOD STATISTICS

	LOGS	
MEAN=	2.320	341.0
STANDARD DEVIATION=	0.484	337.0
SKEWNESS=	-0.677	1.379
STANDARD ERROR OF SKEWNESS=	0.481	

LOG-PEARSON TYPE III CALCULATIONS

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES
0.9900	1.01	9.175
0.9500	1.05	27.749
0.9000	1.11	47.443
0.8000	1.25	86.521
0.5000	2.00	236.780
0.2000	5.00	542.802
0.1000	10.00	784.108
0.0400	25.00	1107.851
0.0200	50.00	1351.852 *** R.I.> 2N
0.0100	100.00	1592.138 *** R.I.> 2N
0.0050	200.00	1826.761 *** R.I.> 2N
0.0020	500.00	2125.818 *** R.I.> 2N

CHEE RIVER AT THA KHON YANG MAHA SARAKHAM (E.8A)   NO. OF ITEMS = 20   STATION 0- 0.28   CODE

DATA USED IN CALCULATIONS

636.000	663.000	808.000	857.000	959.000	684.000	881.000	1108.000	1052.000	1068.000
324.000	571.000	492.000	135.000	785.000	537.000	482.000	186.000	277.000	155.000

ANNUAL FLOOD STATISTICS

	LOGS	
MEAN=	2.731	633.0
STANDARD DEVIATION=	0.282	309.5
SKEWNESS=	-0.998	-0.140
STANDARD ERROR OF SKEWNESS=	0.512	

LOG-PEARSON TYPE III CALCULATIONS

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES
0.9900	1.01	75.970
0.9500	1.05	159.540
0.9000	1.11	225.825
0.8000	1.25	329.435
0.5000	2.00	598.615
0.2000	5.00	935.075
0.1000	10.00	1118.553
0.0400	25.00	1305.754
0.0200	50.00	1417.244 *** R.I.> 2N
0.0100	100.00	1509.059 *** R.I.> 2N
0.0050	200.00	1585.098 *** R.I.> 2N
0.0020	500.00	1666.333 *** R.I.> 2N

LAM PAO AT BAN NONG SONG HONG, KALASIN (E.34)   NO. OF ITEMS = 12   STATION 0- 0.29   CODE

DATA USED IN CALCULATIONS

639.000	336.000	509.000	611.000	194.000	60.000	197.000	467.000	193.000	61.000
73.000	95.000								

ANNUAL FLOOD STATISTICS

	LOGS	
MEAN=	2.314	286.3
STANDARD DEVIATION=	0.390	218.2
SKEWNESS=	-0.168	0.559
STANDARD ERROR OF SKEWNESS=	0.637	

LOG-PEARSON TYPE III CALCULATIONS

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES
0.9900	1.01	22.816
0.9500	1.05	45.082
0.9000	1.11	64.174
0.8000	1.25	97.519
0.5000	2.00	211.232
0.2000	5.00	441.554
0.1000	10.00	640.175
0.0400	25.00	941.449 *** R.I.> 2N
0.0200	50.00	1201.008 *** R.I.> 2N
0.0100	100.00	1489.471 *** R.I.> 2N
0.0050	200.00	1808.194 *** R.I.> 2N
0.0020	500.00	2278.194 *** R.I.> 2N

LAM TA KHONG AT DAMSITE (M.38C) NO. OF ITEMS = 13 STATION 0- 0.30 CODE

DATA USED IN CALCULATIONS

77.000	115.000	107.000	95.000	78.000	104.000	26.000	13.000	13.000	14.000
35.000	13.000	13.000							

ANNUAL FLOOD STATISTICS

	LOGS	
MEAN=	1.571	54.1
STANDARD DEVIATION=	0.414	42.1
SKEWNESS=	-0.040	0.293
STANDARD ERROR OF SKEWNESS=	0.616	

LOG-PEARSON TYPE III CALCULATIONS

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES
0.9900	1.01	3.941
0.9500	1.05	7.679
0.9000	1.11	10.931
0.8000	1.25	16.727
0.5000	2.00	37.484
0.2000	5.00	83.251
0.1000	10.00	125.889
0.0400	25.00	195.145
0.0200	50.00	256.644 *** R.I.> 2N
0.0100	100.00	332.912 *** R.I.> 2N
0.0050	200.00	419.093 *** R.I.> 2N
0.0020	500.00	553.385 *** R.I.> 2N

CHEE RIVER AT WAT THAI KOSUME MAHA SARAKAM NO. OF ITEMS = 19 STATION 0- 0.32 CODE

DATA USED IN CALCULATIONS

684.000	973.000	1017.000	1382.000	713.000	1038.000	1453.000	1322.000	1354.000	308.000
585.000	489.000	127.000	1120.000	583.000	483.000	188.000	285.000	150.000	

ANNUAL FLOOD STATISTICS

	LOGS	
MEAN=	2.774	750.2
STANDARD DEVIATION=	0.336	447.4
SKEWNESS=	-0.726	0.167
STANDARD ERROR OF SKEWNESS=	0.524	

LOG-PEARSON TYPE III CALCULATIONS

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES
0.9900	1.01	65.956
0.9500	1.05	144.902
0.9000	1.11	211.736
0.8000	1.25	323.184
0.5000	2.00	652.257
0.2000	5.00	1153.662
0.1000	10.00	1480.302
0.0400	25.00	1866.057
0.0200	50.00	2129.131 *** R.I.> 2N
0.0100	100.00	2370.536 *** R.I.> 2N
0.0050	200.00	2592.311 *** R.I.> 2N
0.0020	500.00	2858.138 *** R.I.> 2N

CHEE RIVER AT THA PHRA (E16A) NO. OF ITEMS = 17 STATION 0- 0.33 CODE

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D A T A U S E D I N C A L C U L A T I O N S

520.000	1067.000	253.000	343.000	1744.000	1412.000	1840.000	174.000	611.000	334.000
88.000	1655.000	257.000	313.000	165.000	194.000	140.000			

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A N N U A L F L O O D S T A T I S T I C S

	LOGS	
MEAN=	2.627	654.7
STANDARD DEVIATION=	0.420	624.6
SKEWNESS=	0.299	1.046
STANDARD ERROR OF SKEWNESS=	0.550	

L O G - P E A R S O N T Y P E I I I C A L C U L A T I O N S

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES
0.9900	1.01	55.235
0.9500	1.05	93.993
0.9000	1.11	126.925
0.8000	1.25	185.584
0.5000	2.00	403.745
0.2000	5.00	940.336
0.1000	10.00	1504.172
0.0400	25.00	2536.211
0.0200	50.00	3596.994 *** R.I.> 2N
0.0100	100.00	4965.391 *** R.I.> 2N
0.0050	200.00	6714.773 *** R.I.> 2N
0.0020	500.00	9764.969 *** R.I.> 2N

NAM DON AT PHANA NIKOM SAKHCN NAKHON NO. OF ITEMS = 9 STATION 0- 0.34 CODE

****

D A T A U S E D I N C A L C U L A T I O N S

78.000	67.000	78.000	74.000	82.000	70.000	73.000	59.000	65.000

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A N N U A L F L O O D S T A T I S T I C S

	LOGS	
MEAN=	1.854	71.8
STANDARD DEVIATION=	0.045	7.3
SKEWNESS=	-0.588	-0.396
STANDARD ERROR OF SKEWNESS=	0.717	

L O G - P E A R S O N T Y P E I I I C A L C U L A T I O N S

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES
0.9900	1.01	53.718
0.9500	1.05	59.300
0.9000	1.11	62.241
0.8000	1.25	65.743
0.5000	2.00	72.166
0.2000	5.00	78.038
0.1000	10.00	80.936
0.0400	25.00	83.765 *** R.I.> 2N
0.0200	50.00	85.471 *** R.I.> 2N
0.0100	100.00	86.922 *** R.I.> 2N
0.0050	200.00	88.178 *** R.I.> 2N
0.0020	500.00	89.610 *** R.I.> 2N

HUAI KHA YANG AT BAN NAM OON (M.66) NO. OF ITEMS = 10 STATION 0- 0.35 CODE

D A T A   U S E D   I N   C A L C U L A T I O N S

34.000	101.000	60.000	86.000	127.000	98.000	50.000	326.000	32.000	24.000

A N N U A L   F L O O D   S T A T I S T I C S

	LOGS	
MEAN=	1.847	94.0
STANDARD DEVIATION=	0.335	88.3
SKEWNESS=	0.561	2.341
STANDARD ERROR OF SKEWNESS=	0.687	

L O G - P E A R S O N   T Y P E   I I I   C A L C U L A T I O N S

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES	
0.9900	1.01	16.120	
0.9500	1.05	22.606	
0.9000	1.11	27.711	
0.8000	1.25	36.280	
0.5000	2.00	65.376	
0.2000	5.00	130.439	
0.1000	10.00	195.291	
0.0400	25.00	310.487	*** R.I.> 2N
0.0200	50.00	426.797	*** R.I.> 2N
0.0100	100.00	575.482	*** R.I.> 2N
0.0050	200.00	764.674	*** R.I.> 2N
0.0020	500.00	1094.159	*** R.I.> 2N

LAM SAE AT KHON BURI (M.50) NO. OF ITEMS = 10 STATION 0- 0.36 CODE

D A T A   U S E D   I N   C A L C U L A T I O N S

67.000	107.000	102.000	17.000	167.000	16.000	66.000	171.000	66.000	39.000

A N N U A L   F L O O D   S T A T I S T I C S

	LOGS	
MEAN=	1.798	81.8
STANDARD DEVIATION=	0.363	55.1
SKEWNESS=	-0.644	0.586
STANDARD ERROR OF SKEWNESS=	0.687	

L O G - P E A R S O N   T Y P E   I I I   C A L C U L A T I O N S

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES	
0.9900	1.01	6.124	
0.9500	1.05	13.881	
0.9000	1.11	20.668	
0.8000	1.25	32.332	
0.5000	2.00	68.733	
0.2000	5.00	128.736	
0.1000	10.00	170.464	
0.0400	25.00	222.373	*** R.I.> 2N
0.0200	50.00	259.450	*** R.I.> 2N
0.0100	100.00	294.731	*** R.I.> 2N
0.0050	200.00	328.264	*** R.I.> 2N
0.0020	500.00	369.983	*** R.I.> 2N

NAM PHONG AT BAN NONG WAI (E.22A) NO. OF ITEMS = 9 STATION 0- 0.37 CODE

D A T A U S E D I N C A L C U L A T I O N S

129.000	116.000	77.000	104.000	277.000	270.000	87.000	72.000	130.000

A N N U A L F L O O D S T A T I S T I C S

	LOGS	
MEAN=	2.096	140.2
STANDARD DEVIATION=	0.214	78.4
SKEWNESS=	0.860	1.321
STANDARD ERROR OF SKEWNESS=	0.717	

L O G - P E A R S O N T Y P E I I I C A L C U L A T I O N S

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES
0.9900	1.01	54.298
0.9500	1.05	63.622
0.9000	1.11	70.644
0.8000	1.25	81.870
0.5000	2.00	116.315
0.2000	5.00	182.491
0.1000	10.00	240.949
0.0400	25.00	335.155 *** R.I.> 2N
0.0200	50.00	422.753 *** R.I.> 2N
0.0100	100.00	527.768 *** R.I.> 2N
0.0050	200.00	653.718 *** R.I.> 2N
0.0020	500.00	859.448 *** R.I.> 2N

UPPER MUNE AT BAN JORAKHE HIN (M.49) NO. OF ITEMS = 10 STATION 0- 0.38 CODE

D A T A U S E D I N C A L C U L A T I O N S

79.000	28.000	112.000	3.000	115.000	13.000	16.000	276.000	46.000	25.000

A N N U A L F L O O D S T A T I S T I C S

	LOGS	
MEAN=	1.575	71.3
STANDARD DEVIATION=	0.570	82.5
SKEWNESS=	-0.432	1.938
STANDARD ERROR OF SKEWNESS=	0.687	

L O G - P E A R S O N T Y P E I I I C A L C U L A T I O N S

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES
0.9900	1.01	1.178
0.9500	1.05	3.739
0.9000	1.11	6.657
0.8000	1.25	12.917
0.5000	2.00	41.313
0.2000	5.00	115.592
0.1000	10.00	188.075
0.0400	25.00	304.530 *** R.I.> 2N
0.0200	50.00	407.602 *** R.I.> 2N
0.0100	100.00	523.000 *** R.I.> 2N
0.0050	200.00	650.175 *** R.I.> 2N
0.0020	500.00	835.372 *** R.I.> 2N

LAM TA KONG AT NAKHON RATCHSIMA (M43)   NO. OF ITEMS = 10   STATION 0- 0.39 CODE

D A T A   U S E D   I N   C A L C U L A T I O N S

57.000	86.000	59.000	16.000	42.000	27.000	20.000	108.000	29.000	42.000

A N N U A L   F L O O D   S T A T I S T I C S

	LOGS	
MEAN=	1.614	48.6
STANDARD DEVIATION=	0.268	29.7
SKEWNESS=	0.031	0.996
STANDARD ERROR OF SKEWNESS=	0.687	

L O G - P E A R S O N   T Y P E   I I I   C A L C U L A T I O N S

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES	
0.9900	1.01	9.931	
0.9500	1.05	14.990	
0.9000	1.11	18.691	
0.8000	1.25	24.444	
0.5000	2.00	40.984	
0.2000	5.00	69.027	
0.1000	10.00	90.815	
0.0400	25.00	121.846	*** R.I.> 2N
0.0200	50.00	147.438	*** R.I.> 2N
0.0100	100.00	175.108	*** R.I.> 2N
0.0050	200.00	205.048	*** R.I.> 2N
0.0020	500.00	248.410	*** R.I.> 2N

NAM OON AT BAN KHOK SA-AT (KH20B)   NO. OF ITEMS = 9   STATION 0- 0.40 CODE

D A T A   U S E D   I N   C A L C U L A T I O N S

371.000	52.000	66.000	93.000	100.000	146.000	252.000	527.000	283.000

A N N U A L   F L O O D   S T A T I S T I C S

	LOGS	
MEAN=	2.201	210.0
STANDARD DEVIATION=	0.351	161.7
SKEWNESS=	0.087	1.003
STANDARD ERROR OF SKEWNESS=	0.717	

L O G - P E A R S O N   T Y P E   I I I   C A L C U L A T I O N S

EXCEEDANCE PROB	RECURRENCE INTERVAL	MAGNITUDES	
0.9900	1.01	25.532	
0.9500	1.05	42.920	
0.9000	1.11	56.860	
0.8000	1.25	80.259	
0.5000	2.00	157.152	
0.2000	5.00	312.867	
0.1000	10.00	451.424	
0.0400	25.00	670.802	*** R.I.> 2N
0.0200	50.00	868.821	*** R.I.> 2N
0.0100	100.00	1098.499	*** R.I.> 2N
0.0050	200.00	1363.671	*** R.I.> 2N
0.0020	500.00	1775.813	*** R.I.> 2N

APPENDIX C

RELATIONSHIP OF FLOOD PEAKS WITH SELECTED RECURRENCE INTERVAL WITH BASIN CHARACTERISTICS AND CLIMATIC CONDITIONS

TABLE XXXV

LINEAR MODEL EQUATIONS PEAK FLOW RELATED TO FIVE VARIABLES

Model Forms	R^2	Variable	Observed Significant Level > |t|
Q_2 = - 259.24 + 0.03 DA + 0.19 ANRAIN	0.952	DA	0.0001*
- 1.39 LENGTH + 0.15 EVAP		ANRAIN	0.0837
- 0.27 S S		LENGTH	0.1455
		EVAP	0.5645
		S. S	0.7797
Q_5 = 87.54 + 0.04 DA - 2.76 LENGTH	0.945	DA	0.0001*
- 0.12 EL + 0.08 ANRAIN		LENGTH	0.0552
+ 0.13 EVAP		EL	0.5007
		ANRAIN	0.6592
		EVAP	0.6615
Q_{10} = 320.28 + 0.04 DA - 3.79 LENGTH	0.926	DA	0.0001*
+ 1.47 S. S - 0.13 EL + 0.06 EVAP		LENGTH	0.0541
		S. S	0.5244
		EL	0.5939
		EVAP	0.8675
Q_{25} = 852.79 + 0.05 DA - 5.0 LENGTH	0.875	DA	0.0001*
+2.55 S. S - 0.22 ANRAIN		LENGTH	0.0964
- 0.24 EL		S. S	0.5191
		ANRAIN	0.5457
		EL	0.5596
Q_{50} = 1289.83 + 0.06 DA - 5.84 LENGTH	0.809	DA	0.0001*
+ 3.31 S. S - 0.43 ANRAIN		LENGTH	0.1654
- 0.33 EL		S. S	0.5147
		ANRAIN	0.5969
		EL	0.5145

TABLE XXXV (Continued)

Model Forms	R^2	Variable	Observed Significant Level $> \lvert t \rvert$
Q_{100} = 1843.99 + 0.06 DA - 6.51 LENGTH + 4.06 S. S - 0.70 ANRAIN - 0.42 EL	0.716	DA	0.0001*
		LENGTH	0.2704
		S. S	0.5686
		ANRAIN	0.6726
		EL	0.6038

*denotes the significant variable

TABLE XXXVI

LINEAR MODEL EQUATIONS PEAK FLOW RELATED TO FOUR VARIABLES

Model Forms	R^2	Variable	Observed Significant Level $>\lvert t\rvert$
Q_2 = -257.57 + 0.03 DA + 0.19 ANRAIN - 1.42 LENGTH + 0.14 EVAP	0.952	DA	0.0001*
		ANRAIN	0.0805
		LENGTH	0.1273
		EVAP	0.5478
Q_5 = 223.98 + 0.04 DA - 2.65 LENGTH - 0.14 EL + 0.07 ANRAIN	0.944	DA	0.0001*
		LENGTH	0.0581
		EL	0.5918
		ANRAIN	0.666
Q_{10} = 383.95 + 0.04 DA - 3.74 LENGTH 1.50 SS - 0.15 EL	0.925	DA	0.0001*
		LENGTH	0.0505
		SS	0.5086
		EL	0.5602
Q_{25} = 647.42 + 0.05 DA - 4.77 LENGTH 3.58 SS - 0.16 ANRAIN	0.873	DA	0.001*
		LENGTH	0.1058
		SS	0.2468
		ANRAIN	0.6430
Q_{50} = 1012.52 + 0.06 DA - 5.53 LENGTH + 4.70 SS - 0.35 ANRAIN	0.8077	DA	0.0001*
		LENGTH	0.1807
		SS	0.2783
		ANRAIN	0.5219

TABLE XXXVI (Continued)

Model Forms	R^2	Variable	Observed Significant Level > ltl
Q_{100} = 1485.02 + 0.06 DA - 611 LENGTH + 5.86 SS - 0.59 ANRAIN	0.714	DA	0.0001*
		LENGTH	0.2922
		SS	0.6647
		ANRAIN	0.6169

*denotes the significant variable

TABLE XXXVII

LINEAR MODEL EQUATIONS PEAK FLOW RELATED TO THREE VARIABLES

Model Forms	R^2	Variable	Observed Significant Level > |t|
Q_2 = - 123.76 + 0.03 DA + 0.19 ANRAIN	0.951	DA	0.0001*
- 1.26 LENGTH		ANRAIN	0.0742
		LENGTH	0.1611
Q_5 = 331.42 + 0.04 DA - 2.61 LENGTH	0.944	DA	0.0001*
- 0.16 EL		LENGTH	0.0577
		SS	0.3206
Q_{10} = 310.14 + 0.04 DA - 3.56 LENGTH	0.925	DA	0.0001*
+ 2.14 EL		LENGTH	0.0562
		SS	0.2734
Q_{25} = 425.86 + 0.05 DA - 4.92 LENGTH	0.8728	DA	0.0001*
+ 3.53 SS		LENGTH	0.0900
		SS	0.2471
Q_{50} = 535.72 + 0.06 DA - 5.84 LENGTH	0.805	DA	0.0001*
+ 4.60 SS		LENGTH	0.1516
		SS	0.2859
Q_{100} = 668.40 + 0.06 DA - 6.64 LENGTH	0.707	DA	0.0001*
		LENGTH	0.2461
		SS	0.6506

*denotes the significant variable

TABLE XXXVIII

LINEAR MODEL EQUATIONS PEAK FLOW RELATED TO TWO VARIABLES

Model Forms	R^2	Variable	Observed Significant Level $> \|t\|$
$Q_2 = -145.53 + 0.03\ DA + 0.18\ ANRAIN$	0.948	DA	0.0001*
		ANRAIN	0.1055
$Q_5 = 275.42 + 0.04\ DA - 2.31\ LENGTH$	0.942	DA	0.0001*
		LENGTH	0.0838
$Q_{10} = 383.07 + 0.04\ DA - 3.21\ LENGTH$	0.922	DA	0.0001*
		LENGTH	0.0807
$Q_{25} = 546.11 + 0.05\ DA - 4.33\ LENGTH$	0.867	DA	0.001*
		LENGTH	0.1307
$Q_{50} = 692.15 + 0.06\ DA - 5.07\ LENGTH$	0.798	DA	0.0001*
		LENGTH	0.2069
$Q_{100} = 861.73 + 0.06\ DA - 5.69\ LENGTH$	0.699	DA	0.0001*
		LENGTH	0.3133

*denotes the significant variable

TABLE XXXIX

LOGARITHMIC MODEL EQUATIONS PEAK FLOW RELATED TO FIVE VARIABLES

	Model Forms	R^2	Variable	Observed Significant Level > |t|
Log Q_2	= - 5.76 + 0.6 log DA + 1.18 log ANRAIN	0.810	log DA	0.0001*
	+ 0.22 log EL + 0.59 log EVAP		log ANRAIN	0.0514
	- 0.008 log SS		log EL	0.5441
			log EVAP	0.6152
			log SS	0.9571
Log Q_5	= - 2,27 + 0.55 log DA + 0.61 log EVAP	0.800	log DA	0.0001*
	+ 0.27 log ANRAIN + 0.07 log EL		log EVAP	0.6216
	+ 0.03 log LENGTH		log ANRAIN	0.6501
			log EL	0.7395
			log LENGTH	0.8467
Log Q_{10}	= - 1.42 + 0.52 log DA + 0.62 log EVAP	0.777	log DA	0.0001*
	+ 0.06 log LENGTH + 0.1 log EL		log EVAP	0.6012
	0.05 log SS		log LENGTH	0.7431
			log EL	0.7292
			log SS	0.7513
Log Q_{25}	= 0.85 + 0.48 log DA + 0.59 log EVAP	0.734	log DA	0.0001*
	- 0.56 log ANRAIN + 0.11 log LENGTH		log EVAP	0.5890
	0.04 log SS		log ANRAIN	0.6065
			log LENGTH	0.6350
			log SS	0.7422

TABLE XXXIX (Continued)

Model Forms	R^2	Variable	Observed Significant Level	> ltl
Log Q_{50} = 1.64 + 0.46 log DA - 0.80 log ANRAIN + 0.60 log EVAP + 0.13 log LENGTH + 0.05 log SS	0.692	log DA	0.003*	
		log ANRAIN	0.2642	
		log EVAP	0.5093	
		log LENGTH	0.5963	
		log SS	0.7056	
Log Q_{100} = 2.34 + 0.44 log DA - 1.00 log ANRAIN 0.62 log EVAP + 0.16 log LENGTH + 0.06 log SS	0.648	log DA	.0009	
		log ANRAIN	.1965	
		log EVAP	.5199	
		log LENGTH	.5571	
		log SS	.6981	

*denotes the significant variable

TABLE XL

LOGARITHMIC MODEL EQUATIONS PEAK FLOW RELATED TO FOUR VARIABLES

Model Forms	R^2	Variable	Observed Significant Level > $\lvert t \rvert$
Log Q_2 = - 5.8 + 0.6 log DA + 1.19 log ANRAIN + 0.23 log EL + 0.59 log EVAP	0.810	log DA	0.0001*
		log ANRAIN	0.0460
		log EL	0.2690
		log EVAP	0.6220
Log Q_5 = - 2.41 + 0.56 log DA + 0.65 log EVAP + 0.29 log ANRAIN + 0.07 log EL	0.800	log DA	0.0001*
		log EVAP	0.6719
		log ANRAIN	0.6264
		log EL	0.7242
Log Q_{10} = - 0.59 + 0.52 log DA + 0.60 log EVAP + 0.06 log LENGTH - 0.15 log ANRAIN	0.776	log DA	0.0001*
		log EVAP	0.6304
		log LENGTH	0.7451
		log ANRAIN	0.7792
Log Q_{25} = 0.5 + 0.5 log DA + 0.66 log EVAP - 0.51 log ANRAIN + 0.09 log LENGTH	0.732	log DA	0.0001*
		log EVAP	0.6245
		log ANRAIN	0.5826
		log LENGTH	0.6604
Log Q_{50} = 1.2 + 0.47 log DA - 0.73 log ANRAIN + 0.69 log EVAP + 0.12 log LENGTH	0.690	log DA	0.0001*
		log ANRAIN	0.2836
		log EVAP	0.6047
		log LENGTH	0.6260

TABLE XL (Continued)

Model Forms	R^2	Variable	Observed Significant Level	> |t|
$\text{Log } Q_{100}$ = 1.83 + 0.46 log DA	0.646	log DA	0.0001*	
- 0.94 lot ANRAIN		log ANRAIN	0.405	
+ 0.72 log EVAP		log EVAP	0.5782	
+ 0.14 log LENGTH		log LENGTH	0.5865	

*denotes the significant variable

TABLE XLI

LOGARITHMIC MODEL EQUATIONS PEAK FLOW RELATED TO THREE VARIABLES

Model Forms	R^2	Variable	Observed Significant Level > |t|
$\log Q_2 = -3.83 + 0.61 \log DA$	0.806	log DA	0.0001*
$+ 1.17 \log ANRAIN$		log ANRAIN	0.0487
$+ 0.17 \log EL$		log EL	0.6059
$\log Q_5 = -1.71 + 0.54 \log DA$	0.799	log DA	0.0001*
$+ 0.57 \log EVAP$		log EVAP	0.6441
$+ 0.21 \log ANRAIN$		log ANRAIN	0.6984
$\log Q_{10} = -1.1 + 0.52 \log DA$	0.776	log DA	0.0001*
$+ 0.59 \log EVAP$		log EVAP	0.6259
$+ 0.06 \log LENGTH$		log LENGTH	0.7612
$\log Q_{25} = 0.23 + 0.52 \log DA$	0.731	log DA	0.0001*
$+ 0.74 \log EVAP$		log EVAP	0.2981
$- 0.48 \log ANRAIN$		log ANRAIN	0.5636
$\log Q_{50} = 0.86 + 0.51 \log DA$	0.688	log DA	0.0001*
$- 0.70 \log ANRAIN$		log ANRAIN	0.2992
$+ 0.79 \log EVAP$		log EVAP	0.3100
$\log Q_{100} = 1.43 + 0.50 \log DA$	0.643	log DA	0.0001*
$- 089 \log ANRAIN$		log ANRAIN	0.2246
$+ 0.84 \log EVAP$		log EVAP	0.6738

*denotes the significant variable

TABLE XLII

LOGARITHMIC MODEL EQUATIONS PEAK FLOW RELATED TO TWO VARIABLES

Model Forms	R^2	Variable	Observed Significant Limit $> \lvert t \rvert$
$\text{Log } Q_2 = -2.67 + 0.58 \log DA$	0.801	log DA	0.0001*
$+ 0.96 \log ANRAIN$		log ANRAIN	0.0727
$\text{Log } Q_5 = -1.14 + 0.55 \log DA$	0.798	log DA	0.0001*
$+ 0.60 \log EVAP$		log ANRAIN	0.3233
$\text{Log } Q_{10} = -1.15 + 0.54 \log DA$	0.775	log DA	0.0001*
$+ 0.64 \log EVAP$		log EVAP	0.3106
$\text{Log } Q_{25} = -1.11 + 0.52 \log DA$	0.726	log DA	0.0001*
$+ 0.68 \log EVAP$		log EVAP	0.6633
$\text{Log } Q_{50} = 2.95 + 0.53 \log DA$	0.678	log DA	0.0001*
$- 0.62 \log ANRAIN$		log ANRAIN	0.6447
$\text{Log } Q_{100} = 3.64 + 0.52 \log DA$	0.633	log DA	0.0001*
$-0.81 \log ANRAIN$		log ANRAIN	0.2679

*denotes the significant variable

VITA

Pirote Kriengsiri

Candidate for the Degree of

Doctor of Philosophy

Thesis: A METHODOLOGY FOR ESTIMATING THE REGIONAL FLOOD FREQUENCIES FOR NORTHEASTERN THAILAND

Major Field: Civil Engineering

Biographical:

Personal Data: Born on July 4, 1946, in Bangkok, Thailand, the son of Eam and Nit Kriengsiri.

Education: Graudated from Bangkok Christian College, Bangkok, Thailand, in 1963; received Bachelor of Engineering degree from Kasetsart University, Bangkok, in April, 1969; completed requirements for the Master of Science degree in Civil Engineering from the University of Missouri at Rolla, Rolla, in May, 1971; part-time graduate student at Georgia Institute of Technology, Atlanta, Georgia, 1971-1972; completed requirements for the Doctor of Philosophy degree in Civil Engineering at Oklahoma State University, Stillwater, in July, 1976.

Professional Experience: Engineer in the Royal Thai Irrigation Department, Bangkok, Thailand, 1967-1969; graduate student assistant, Georgia Institute of Technology, 1971-1972; graduate teaching assistant, Oklahoma State University, 1974-1976.